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SUNNYVALE, CALIFORNIA

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5 January 1970

LARGE TELESCOPE EXPERIMENT

PROGRAM (LTEP)

FINAL TECHNICAL REPORT

Volume II Technical Proposal

Submitted to:
The Perkin-Elmer Corporation
Norwalk, Connecticut

Covering effort performed under Subcontract 62504-PN
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with
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Huntsville, Alabama

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Approved by ______________

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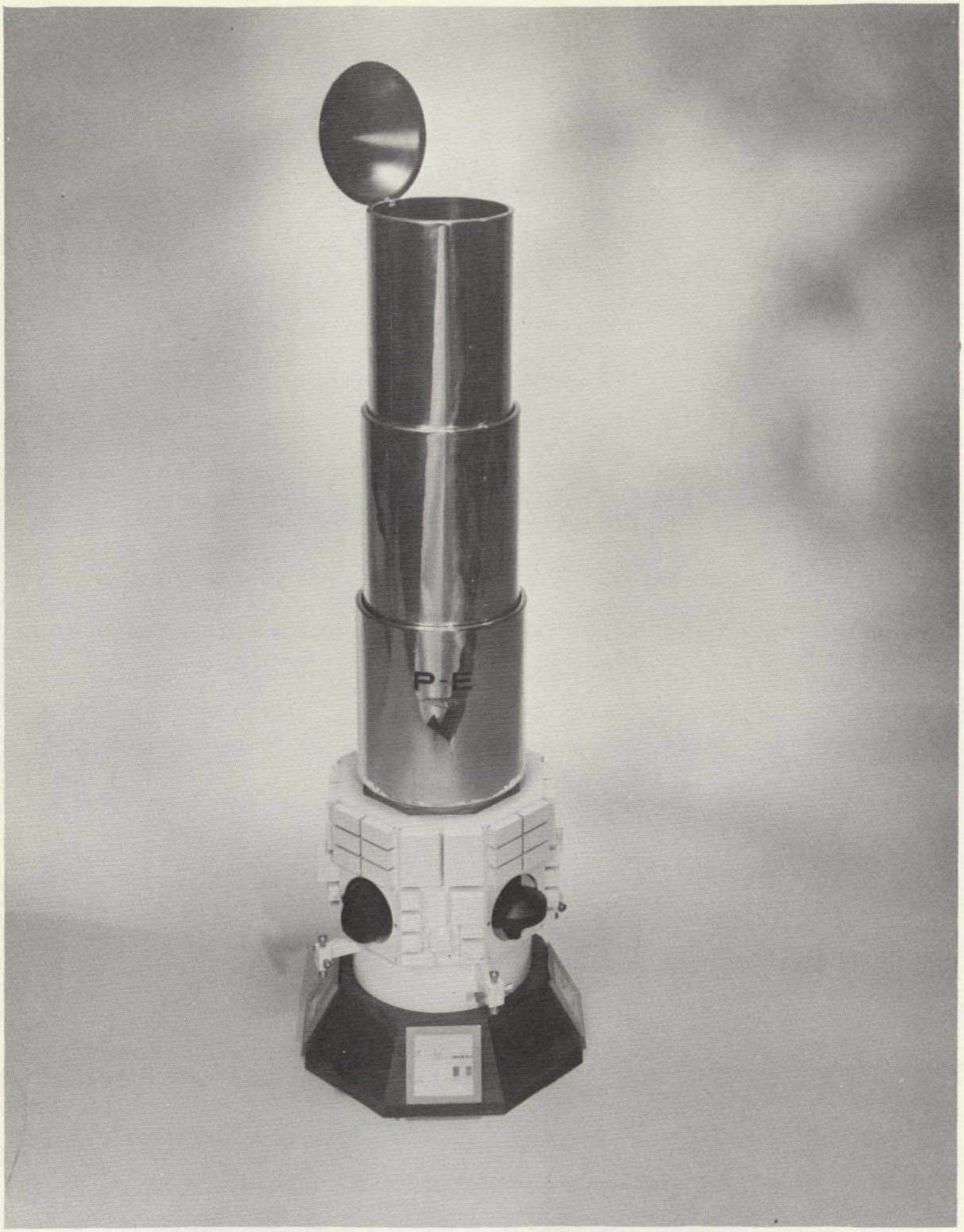

Frontispiece: The 2-Meter LTEP Configuration

FOREWORD

The Lockheed Missiles & Space Company (LMSC), Sunnyvale, California, in support of the Perkin-Elmer Corporation, Norwalk, Connecticut, performed the three-part Optical Technology Experiment System (OTES) Phase A study in the period 1965 to 1967. These studies considered various possible approaches to implementing alternate space telescope configurations. A primary result of these conceptual design considerations was the generation of a spacecraft/2-meter telescope configuration which indicated the feasibility of implementing this system.

In July of 1969, LMSC initiated effort on a follow-on study of the 2-meter system in support of Perkin-Elmer efforts on the Large Telescope Experiment Program (LTEP). These analyses and considerations of the spacecraft and related areas of program support were based, primarily, on the basic configuration described in LMSC Report No. A848294, "Optical Technology Experiment System (OTES), Phase II – Final Technical Report", dated 15 September 1967. Subsequent developments have included NASA selection of the AAP Saturn dry workshop (SWS) cluster configuration, evolution of the space shuttle/space station, and adaption of the optical experiments for space astronomy technology development and astronomy operation. The LTEP study has reviewed and updated the results of the previous OTES effort, integrated consideration of the subsequent developments and defined the areas for technical concentration in an early Phase B follow-on study program.

The results of the LTEP spacecraft support study are summarized in this Final Report input. The feasibility of the 2-meter concept has been validated, the configuration modified consistent with the current AAP system, alternate operating modes defined and a firm basis established for a Phase B Large Stellar Telescope (LST) study program.

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Section 1

SUMMARY

1.1 RESULTS OF STUDY

The study objectives were met as follows:

Feasibility. The 2-meter system can be implemented, with a minimum of development risks, in either the piggyback or independent (autonomous) modes that were considered. The principal difficulty envisioned in accomplishing the program is a critically spanned schedule if a July 1974 SWS-II launch date is maintained. This criticality is significantly reduced in meeting a mid-1975 or subsequent commitment.

Remote (i.e., detached or free-flying) operation requires development of a new equipment unit for mounting of existing propulsion, electrical, and communication subsystem hardware. This containment structure, designated the Propulsion and Support Module (PSM), is not considered a major problem. Implementation of the autonomous concept in a manned operational mode requires development of the Manned Orbital Telescope Experiment Laboratory (MOTEL) system. This life cell support system is a minimum-development, simplified unit providing a shirt-sleeve, visor-up environment for one or two astronauts for periods up to 3 to 4 hours. A more elaborate system designated HOTEL (Habital Orbital Telescope Experiment Laboratory) is envisioned for use with the space station in the detached operating mode. This more advanced system would permit manned operation of up to 30-day periods.

Implementation Recommendation. As previously indicated, either of the piggyback approaches or the independent concepts are considered feasible. Further, the basic 2-meter telescope configuration will readily adapt to these various operational approaches. Thus, the basic decision as to the optimum program implementation need not be completed prior to continued effort on the system. Phase B effort can proceed on the basic configuration with equal applicability to the ultimate mode of implementation. A programmatic selection will be required at the end of Phase B effort (i.e., late CY 1970). This is particularly true if the earliest flight date (July 1974) is selected for the telescope launch. Early development of the basic 2-meter telescope configuration with the Propulsion and Support Module is recommended.

Phase B Effort. The five key items to be accomplished in the spacecraft support areas in performing the Phase B (definition) program are refinement of the attitude control and stability analysis, quantitative evaluation of outgassing effects, structural and dynamic analysis of the spacecraft system, evaluation of the lifetime potential of critical system elements and further definition of the astronaut operations and requirements for manned support. In addition, the generated preliminary resources planning data can be modified and/or supplemented to facilitate program evolution. This refinement, however, can be made more meaningful upon completion of the NASA decision as to the final mode of program implementation.

Several key LTEP study results that were derived in obtaining the above three principal conclusions evolved from the various support study analyses. For example, launch vehicles were compared and examined and the Saturn V, Titan IIIC and Saturn IB systems selected for appropriate modes of implementation. The 220-nm, 35 deg inclined, orbit parameters were defined. The results of the thermal analysis can be summarized as follows:

a. The conclusions of the previous analyses were reconfirmed; the 2-meter telescope temperature gradient across the mirror will be held to less than $1^{\circ}C$ utilizing passive techniques. This result applies to both the cluster-docked and autonomous (independent) modes of operation.

b. The on-station thermal environment is as previously defined. The "desirable" operating temperature from a spacecraft consideration viewpoint is essentially the same as the previously indicated mirror required operating temperature, i.e., $-80^{\circ}C$. Operational temperatures from $-62^{\circ}C$ to $-93^{\circ}C$ were obtained dependent on the assumed mode and sun angle with a primary mirror temperature level of $-84^{\circ}C$ for the minimum environment and $-71^{\circ}C$ for the maximum.

c. The Optical Solar Reflector (OSR) is a stable thermal control surface material with negligible degradation properties. No life-time problems are anticipated.

d. Continual operation at extremely low temperatures (e.g., $-200^{\circ}C$) is not considered practical. A minimal temperature of approximately $-96^{\circ}C$ might be maintained passively in a synchronous altitude orbit and $-89^{\circ}C$ in low earth orbit.

The following summarizes the impact of an LTEP-ATM application upon astronaut considerations as compared with the current solar ATM operations as indicated from analyses of manned operations:

a. The requirements for astronaut scientific and manual control skills are reduced.

b. There are minimum IVA and control procedures changes.

c. There is an added EVA requirement, but it is a logical next step from the first cluster EVA requirements.

d. The quiescence requirement during telescope operation adds a major crew activity scheduling restriction.

e. There are minimum requirements for new or modified crew systems and training equipment.

Resources review and analyses resulted in a baseline schedule in support of a 1975 launch. A July 1974 launch might be accommodated but would involve cricitically-spanned effort. Preliminary cost plans indicate program requirements between \$91M for the simplest (unmanned) implementation mode and \$134M for the independent, manned concept. The baseline program with the SWS-II would require approximately \$100M including AAP support effort.

Appendix A summarizes the results of a preliminary analysis of the various sources of outgassing and other "contaminant" emissions in the LTEP system. It covers both the AAP Cluster-attached mode and the Independent mode of orbit operation. Primary attention was paid to examination of the types and quantities of emission products and an explanation of their origin. Secondary attention was devoted to preliminary assessment of the effect of these contaminants upon optical surfaces and other critical surfaces such as solar arrays, thermal control surfaces, sensor lenses, and antenna surfaces. It appears there is a potential problem with optical surface contamination, mainly by water vapor. Based upon preliminary analyses, however, and compared with the relative insity of 12th-magnitude stars, the various contaminants stacked in the telescope field of view do not seem particularly troublesome. Additional analysis and/or testing is required to (a) establish quantitative values for emission products, and (b) determine the specific effect on critical surfaces and field-of-view distortions or dilutions. Detailed recommendations for this additional effort are contained in Section 6.

Extensive consideration was given to the spacecraft and subsystem concepts. Some principal conclusions resulting from these analyses are:

a. The AAP Dry Workshop Cluster approach offers a significant improvement in adaptation of the LTEP system to the orbiting-cluster program. The elimination of the LM Ascent Stage allows application of a simplified and versatile LTEP Propulsion/Support Module (PSM) both on the Cluster-attached and Independent missions.

b. The basic ATM Rack appears usable for the LTEP system mounting with only minor structural modifications and equipment relocations (relocation of equipment boxes on the top bulkhead to the vertical side panels of the Rack.)

c. There appear to be definite advantages in a change from a 6-section to a 3-section telescope (this is the change allowed by increased payload packaging volume on the Dry Workshop Cluster piggy-back launch):

- Lighter Weight (fewer rings)
- Simpler Extension Mechanism
- Greater Rigidity
- Reduced Structural Misalignment
- Improved Mounting of Secondary Mirror (on non-folding support rods).

d. The mounting of the launch-stowed telescope with the tube extension pointing "up" provides improved launch/ascent load sustaining by the launch caging mechanisms (major axial loads tend to retract rather than extend the telescope, placing much smaller loading on the caging structure/devices.)

The orbital propulsion subsystem is a straightforward adaption of existing components with the exception of the propellant tanks which have been sized for the LTEP module (2, 600 lb usable propellant). Elements of the tanks (standpipe, bladders, etc.) have been space-qualified.

Several basic conclusions were derived from examination of the standby and operating mode power requirements:

a. Neither the Cluster/LTEP nor the Independent LTEP can be operated with fixed solar arrays.

b. The lightest-weight solar array concept for the Cluster/LTEP results from the use of single-axis pivot (360 deg rotation) on both ATM and OWS solar arrays combined with Cluster/LTEP rotation about the telescope line-of-sight for sun-line aiming of solar arrays.

c. Use of four solar array wings on the LTEP (ATM), for either Cluster-attached or Independent operation is inefficient. Using two wings and mounting at 90 deg to the longitudinal axis of the Cluster and telescope offers a minimum-weight approach with no shadowing effects; this concept is recommended.

d. Two of the existing ATM solar arrays combined with nine of the ATM batteries can provide required electrical power for LTEP in the Independent mode. In the Cluster-attached mode, where the Cluster subsystems are substituting for the LTEP subsystems (attitude control, communications, et al.), the electrical loads are lower, and some of the wattage can be made available to the Cluster via the existing power transfer devices for supplementing the CSM support power (CSM docked with fuel cells dormant).

e. The life expectancy of the proposed solar array/battery system is at least 2 years, limiting the battery discharge depth to a maximum of 30 percent. Extrapolation of operating time beyond that period is difficult because of the small amount of data available on long-term orbit degradation of solar arrays. Actual testing with a simulated environment and analytical review of data and hardware from similar spacecraft programs will be necessary to justify estimates of longer duration operation without replacement.

The basic results of the guidance analysis effort are (a) that the output frequency of the gimbal control system is approximately 2.5 cps and (b) that the output amplitudes are ±1.77 arc sec in the planes including the X and Y axes and ±38 arc sec about the Z (roll) axis of the telescope. Spectral distribution of the major error inputs to the telescope from the gimbal remains to be derived. LMSC has also made a worst-case rough analysis of the distortions which might occur to the telescope tube as a result of the orbit thermal environment and has estimated the gross movements of the tube-end figure sensor and the secondary mirror relative to the primary mirror. The results of this preliminary analysis and initial distortion estimates, hopefully, will assist in making corollary estimates of optical pointing actuator/servo loop requirements to compensate for these potential optical element motions.

With respect to the Communications and Instrumentation Subsystem (C&I) evaluation, the following conclusions were reached:

a. The currently planned AAP Dry Workshop Cluster has adequate capacity and capability for handling all of the LTEP system communications and data processing functions with the exception of the TV network.

b. If it is planned to transmit high-resolution (up to 5000 lines per frame) reproduction of stellar-field photos by TV to ground stations, a multiplexer quantizer element would be added to the existing circuitry to allow pulse-coding and digital transmission of high bit-rate data. The current Cluster system handles the TV (small hand-held camera) on analog.

c. The proposed LTEP Communication and Instrumentation (C&I) subsystem comprises a number of existing components which are space-flight qualified. Some are from the Apollo CM system with the remainder from spacecraft produced by LMSC.

d. A primary potential problem exists in selection of proven hardware. Most of the Apollo program hardware was designed and tested to a 200 hour operating-life specification. The aforementioned LMSC program hardware, in most cases, is designed and tested to either a 6-month or a 9-month operating life specification. Many of these hardware elements are probably capable of longer operating periods, but there is presently no validation of this capability by analysis, testing, nor operating experience. With the two-year minimum life required by the LTEP system, and considering the potentially large benefits of using proven hardware (even with shorter operating life), it appears mandatory that a strong effort should be initiated to investigate in detail the long-life expectancy of the available hardware tentatively selected for the LTEP system (or equivalent).

e. The Manned Space Flight Network (MSFN) ground stations to be utilized with the AAP Cluster are adequate also for the Cluster/LTEP and independent LTEP orbiting systems. Ground contact periods per station will vary from 4 to 8 minutes, quite sufficient for the LTEP system (or Cluster/LTEP) data dumps.

The cumulative effect of the results and conclusions derived during the LTEP support study effort and summarized above were to reconfirm program feasibility, further define the recommended concept and isolate study areas for Phase B analysis.

1.2 SPACECRAFT STUDY STUDY GUIDELINES AND CONSTRAINTS

As a principal guideline, the proposed system will use a 2-meter diameter, seven segment, active-optics primary mirror telescope system and will mate with the Apollo Telescope Mount (ATM) rack. The primary mode of operation is in the AAP Saturn dry workshop (SWS-II) Cluster although operating modes with the early space station and independent of any earth-orbiting manned cluster system were considered. Only stellar target orientation was assigned for the telescope system. The resulting concept and recommended program will establish firm data that can serve for either a technology development system or an early operational space astronomy instrument.

The following guidelines were used for the LTEP spacecraft support study:

- A 1974-75 time frame was assumed for the SWS II and independent mode launches; the space shuttle and/or space station piggyback approaches were based upon initial launch operations in the 1976-77 time frame.

- A minimum of 2-years operation of the system is required; a ten-year on-orbit capability is desired when periodic resupply and maintenance is provided.

- The program will be implemented with a maximum economy and probability of success by using "off-the-shelf" hardware and techniques to eliminate development of experiment support hardware to as great a degree as feasible.

- Reliability will be in full compliance with AAP objectives for a system (mission) goal of 0.90 and a crew survival goal of 0.999.

- The AAP SWS-I mission plans for crew rotation periods will apply to the LTEP mission. Crew tasks include direct or remote experiment operations, equipment maintenance and operations, mirror segment removal, and film replacement and retrieval.

- The thermal gradients (radial) across the primary mirror will not be in excess of $1^{o}C$. The operating temperature will be on the order of $-80^{o}C$. The attitude control and pointing system shall provide a ±2.5 arc sec accuracy.

- The nominal AAP orbit (22 nm circular, 35 deg inclined) is assumed for the system. (Possible space station orbits of 250 to 350 nm and 50 to 55 deg inclinations should not significantly affect feasibility implications of the system concept.)

The study goal has been to consider two alternate means of implementing the 2-meter configuration; as a piggyback on an existing NASA manned program or as an autonomous, independent program effort. As a result of study program efforts, the baseline mode of operation involves the Apollo Applications Program (AAP) with the Saturn launch vehicle family. (The early space station, leading to the spacebase, and using the space shuttle vehicle was also considered as a piggyback-program potential.) Both hard-docked, i.e., an integral portion of the AAP cluster configuration, and subsequent detached (remote) operation is involved in the baseline mode. Three alternatives to this baseline approach were also considered.

For the independent or autonomous approach, a Titan IIIC launch vehicle and appropriate unmanned LTEP configuration was selected. This launch vehicle could also be used to separately launch the LTEP for subsequent rendezvous with the AAP cluster as a secondary AAP experiment mode of operation. An independent manned/astronaut-supported operation was considered. This system involves use of the LMSC-conceived Manned Orbital Telescope Experiment Laboratory (MOTEL). The MOTEL concept was previously described in LMSC/A820889, "Optical Technology Experiment System (OTES), Phase I Final Technical Report", dated 1 September 1966.

The overall study objectives can be summarized as follows:

- Validate feasibility of implementing the 2-meter system in either a piggyback or an independent (autonomous) configuration.
- Select (recommend) a baseline LTEP implementation approach.
- Define the technology efforts required to initiate the recommended implementation.

These study objectives have been accomplished. The resulting baseline system and alternative modes of operation are described in subsequent sections.

1.3 REPORT CONTENTS

The overall approach, reference orbit and mission requirements are given in Section 2. This data is provided as a basis for the spacecraft system description given in Section 3 which contains five elements:

- Overall Configuration
- Launch, Ascent and Erection
- Program Peculiar Elements
- Spacecraft Subsystems

Section 3 describes the spacecraft as configured for the baseline SWS-II operating mode. Alternate operating modes are described in Section 4.

Various analyses performed in support of the spacecraft system are delineated in Section 5. These include the launch vehicle and performance, thermal, and astronaut participation aspects of the study. The spacecraft resources analyses, indicating schedule and cost estimates for implementing the total program, are also given in Section 5. Section 6 provides a summary of recommended future program activities; Section 7 is a listing of applicable references.

Section 2

LTEP MISSION PROFILE

2.1 BASELINE PROGRAM

The operational modes considered for evaluation of the LTEP concept are shown in Fig. 1. The baseline mode of operation is the AAP Saturn Workshop (the SWS-II LTEP) approach. The derivation of the recommended LTEP system, compatible with the present AAP dry workshop (DWS), from the OTES launch arrangement presented in Reference 7-11 is described in the following paragraph, followed by a summary description of this mode. Alternate modes are described in Section 4.

2.2 CONCEPT COMPARISON STUDIES

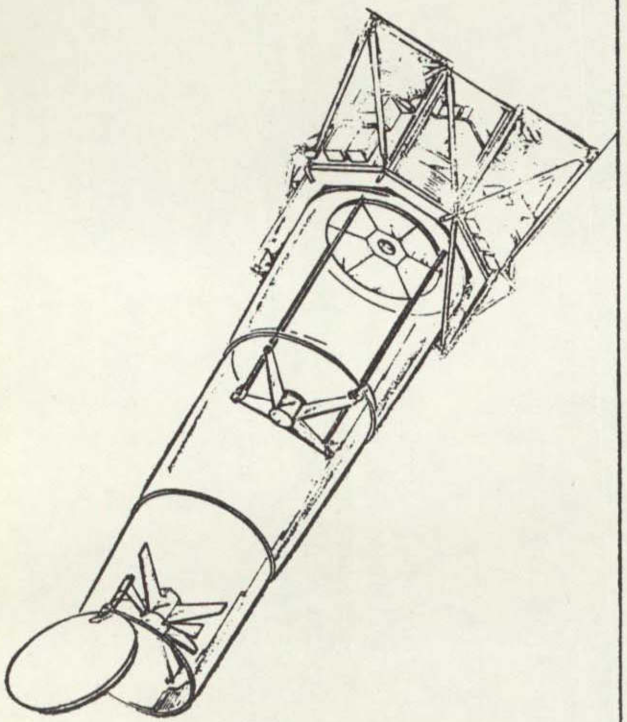
The previously proposed OTES 2-meter telescope design (Ref. 7-11) was constrained by the available payload volume of the Saturn IB launch vehicle and payload fairing. The decision by NASA in mid-1969 to change over to the "Dry Workshop" concept for the AAP Cluster provided considerably more payload volume and allowed reconcepting of the telescope stowed configuration.

2.2.1 OTES Launch Arrangement

The initial launch-stowed configuration resulting from the 1967 study is shown in Fig. 2. The ATM Rack was mounted on the SLA support ring and supported the total payload. The LM Ascent Stage and an Orbital Mirror Recoating Facility (OMRF) were mounted above the ATM Rack and the OTES Telescope Assembly was "hung" below the Rack. The stowed height of the telescope was limited to the space between the ATM Rack and the forward dome of the SIVB tank structure.

2.2.2 OTES 6-Section Telescope

The relatively short stowed-length allowance dictated a design comprising six telescope tube sections. Also, the quartz spacer rods between the primary mirror base and the secondary mirror and support structure had to be hinged and folded in the stowed position. A considerable amount of detailed conceptual design effort was accomplished on this 6-section telescope and it has been used as a point-of-departure for the current studies. The telescope assembly is shown in Fig. 3.



MODE	DESIGNATION	DEFINITION
1	THE SWS-II LTEP (AAP SATURN WORKSHOP)*	o LAUNCHED ON SAT. V WITH SWS-2 o INITIAL OPERATION HARD-DOCKED; MANNED SUPPORT o SUBSEQUENT OPERATION DETACHED (REMOTE) o REDOCKING FOR MANNED RESUPPLY/ MAINTENANCE
2	THE TITAN IIIC LTEP (INDEPENDENT/UNMANNED)	o LAUNCHED ON TITAN IIIC o UNMANNED OPERATION (NO RESUPPLY OR FILM RECOVERY)
3	THE RENDEZVOUS LTEP (INDEPENDENT LAUNCH -- CLUSTER OPERATION)	o LAUNCH ON TITAN III C o DOCK TO AAP CLUSTER—MANNED OPERATION o SEPARATE FOR UNMANNED REMOTE (DETACHED) OPERATION o REDOCKING FOR MANNED RESUPPLY/ MAINTENANCE
4	THE SATURN IB LTEP (INDEPENDENT LAUNCH— MANNED CAPABILITY)	o LAUNCH ON SAT. IB WITH MOTEL o MANNED OPERATION WITH CSM o UNMANNED OPERATIONAL SPAN o CSM RESUPPLY AND MAINTENANCE

*THE CONCEPTUAL DESIGN IS INHERENTLY ADAPTABLE TO OPERATION AS A SPACE SHUTTLE OR SPACE STATION EXPERIMENT IN A MANNER SIMILAR TO THE SATURN/AAP SYSTEM

Fig. 1 LTEP Operational Modes

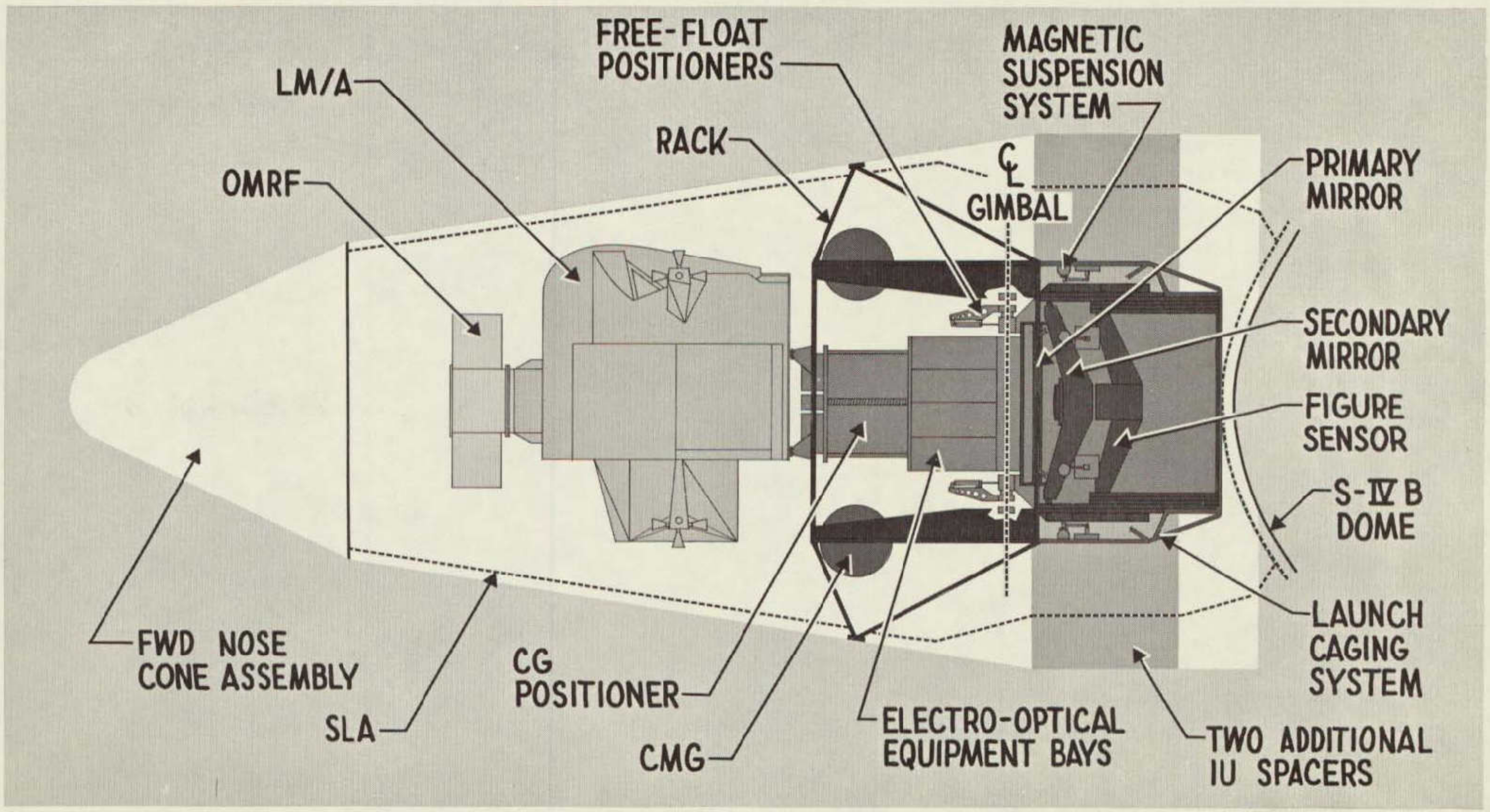


Fig. 2 Initial Launch Configuration for Saturn IB

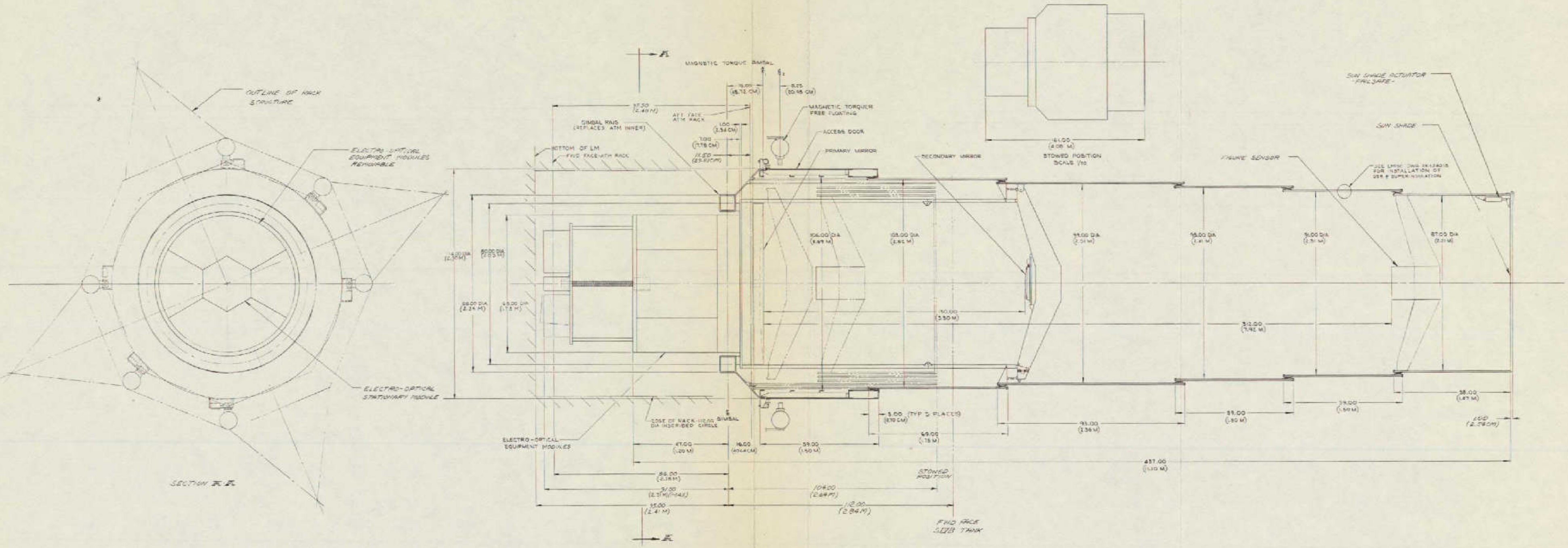


Fig. 3 6-Section Telescope Assembly

FOLDOUT FRAME 1

FOLDOUT FRAME 2

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2.2.3 Influence of New AAP Dry Workshop

With the change by NASA to the Dry Workshop principle, the LM Ascent Stage was eliminated from the AAP Cluster operations. The ATM Rack and the Solar Telescope are mounted atop a new support truss and swing links forward of the SIVB, the Airlock Module (AM), and Modified Docking Adapter (MDA). A new, large-volume payload shroud is provided to house the payload elements during launch and ascent. Figure 4 is an illustration of the ATM Rack and 6-Section (stowed) telescope mounted within the new payload enclosure (fairing).

2.2.4 Simplification of Telescope Sectioning and Extension

Because of the elimination of the LM Ascent Stage and the OMRF (removed after analysis indicated recoating of mirrors could not be accomplished at the low Earth-orbiting altitude because of oxidation of coating by residual oxygen in the 220 nm environment), the telescope assembly can be mounted above the ATM Rack. The primary axial-aft launch loads will not tend to extend the telescope; the external caging/restraint frame provided on the OTES concept can therefore be simplified and/or lightened considerably. The larger longitudinal space also allows reduction in the quantity of telescoping sections. Figure 5 illustrates 2-section and 3-section telescope concepts. The critical-clearance condition for fit within the applicable payload fairings occurs at the forward maximum-diameters of the stowed envelopes. The relative dimensions (measured from a common gimbal centerline) are:

	Diameter (in.)	Length (from Gimbal ℄, in.)
6-Section	133	70
3-Section	115	153 to 163
2-Section	115	205

Because of a major reduction from six to three sections and the attainment of rigid (non-folding) secondary mirror support rods; it was determined that the 2-section concept did not offer significant additional advantages to merit a further 42 to 52 inch increase in telescope stowed envelope and corresponding increase in payload fairing length. The 3-section telescope concept was therefore selected as the baseline for further study.

2.3 THE SWS-II LTEP (SATURN WORKSHOP) – MODE 1

The primary operational mode for application of the LTEP system consists of launching the LTEP Module rigidly attached to the AAP Workshop Cluster and utilizing the Cluster as an orbiting platform. Alternate operation within this basic mode will include release of the LTEP Module from the Cluster and freeflight of the Module in station-keeping relationship to the Cluster.

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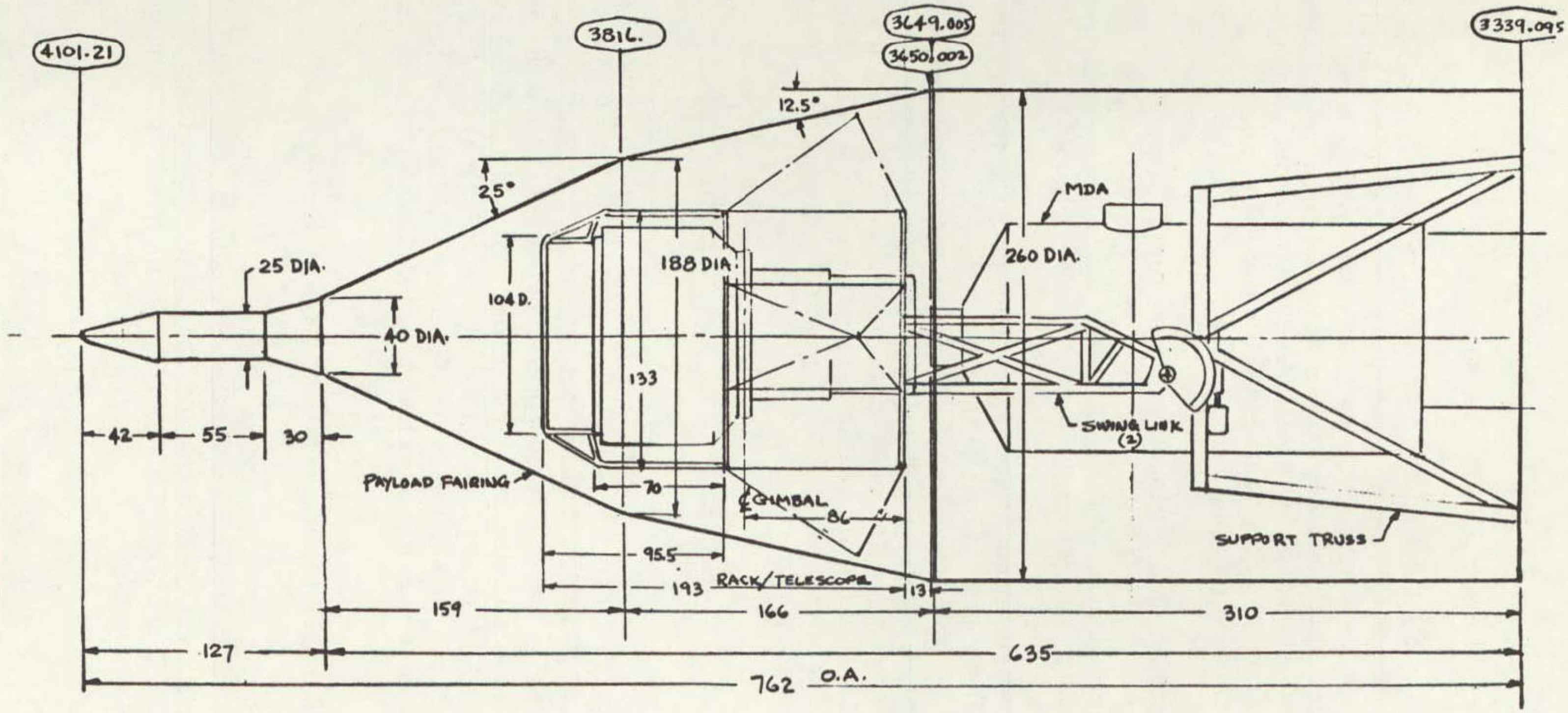


Fig. 4 6-Section Telescope Mounted Within Dry Workshop Payload Fairing

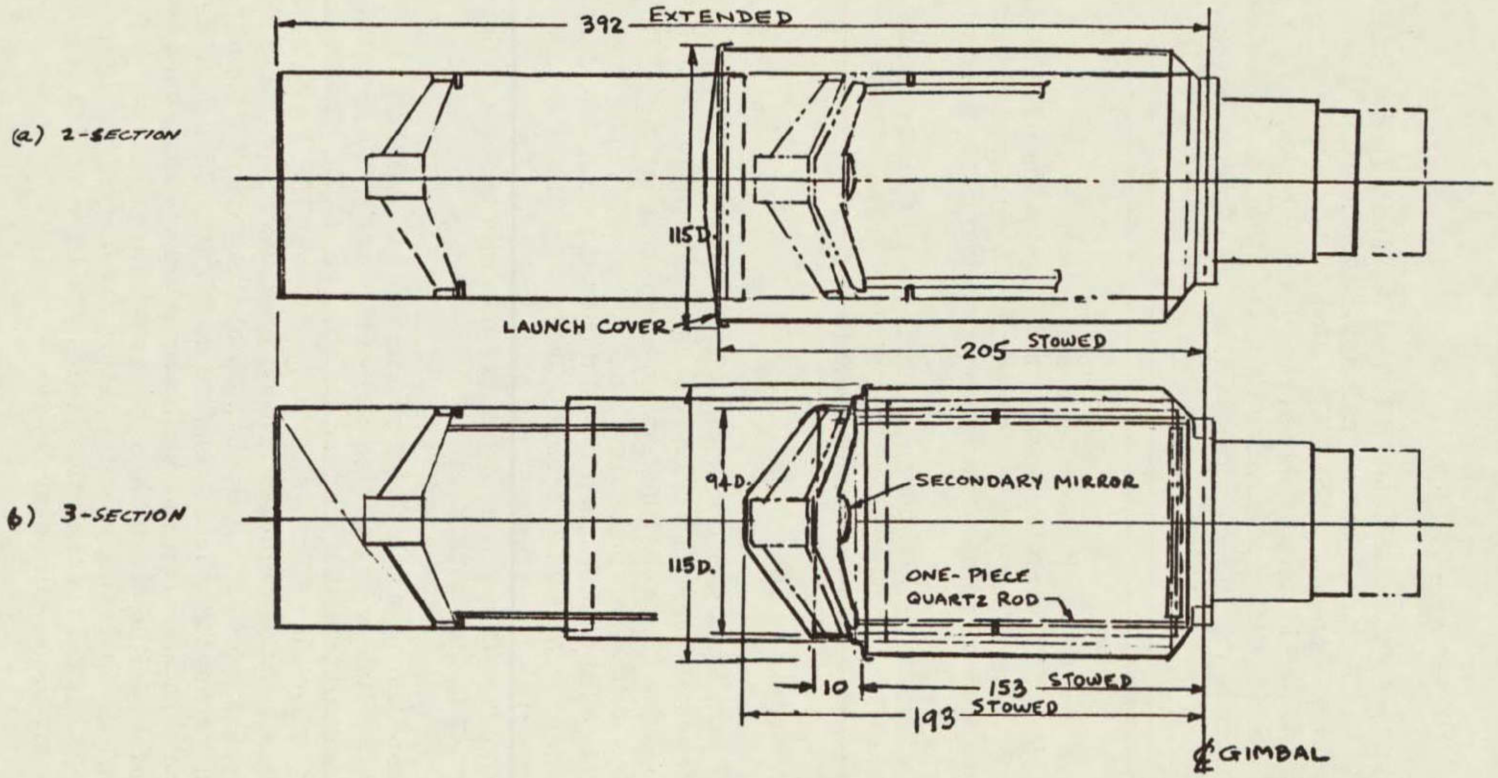


Fig. 5 Envelopes for 2-Section and 3-Section Telescopes

2.3.1 Cluster Vehicle Utilization

Saturn V derivatives, stages SIC and SII, will be used to boost the Dry Workshop Cluster to the 220 nm orbit. The overall launch configuration, including the LTEP Module, is shown in Figure 6. The LTEP Module comprises a Propulsion/Support Module, a modified ATM Rack, solar arrays (folded for launch), and the LTEP Telescope Assembly. After separation from the SII stage at the "separation line" shown and jettison of the 762-inch long fairing, the Cluster is ready for initial operations (preceding crew arrival in a separately launched Apollo CSM).

2.3.2 Orbit Sequence

The sequence of events for the coordinated Dry Workshop Cluster and CSM launches are shown in Fig. 7. The orbiting configuration (with the ATM Solar Telescope) is shown in Fig. 8. The swing-link mechanism has been actuated to reposition the ATM Rack/Telescope 90 deg and the CSM is shown docked to the forward port on the MDA.

The sequence of events will be the same for the AAP Cluster/LTEP combination. The Cluster configuration (Workshop, Airlock Module, MDA, CSM) also will be identical for the Cluster/LTEP mission as with SWS-I.

2.3.3 Requirements and Constraints

Utilizing the Saturn V booster elements, launch azimuths for the LTEP mission are limited to the normal range-safety constraints (generally 45 deg up to 110 deg). However, to achieve the orbital inclination of interest for the LTEP system, at 35 deg, launch azimuths well within these limits may be used. A launch window of one hour is available by accepting a tolerance of ±7.5 deg on the initial right ascension of the of the ascending node, assuming a fixed launch azimuth and no yaw steering. Such a tolerance seems reasonable because the orbit will have a nodal regression rate of 6.57 deg per day inertially, or 7.56 deg per day with respect to the sun. A cycle with respect to the sun is then completed in 47.6 days.

In the piggy-back launch of the LTEP system on the AAP Cluster, the selected launch profile places the Cluster/LTEP into a circular orbit, 220 nm altitude, with 35 deg inclination, launched from the Eastern Test Range (ETR). The Saturn V launch vehicle derivative (SIC stage plus SII stage) with the Cluster/LTEP would be the first of several launches. No known launch window nor launch period requirements are imposed on the launch. More detailed analysis possibly may identify some requirements which result indirectly from the manned rendezvous with the CSM (launched separately on a Saturn IB launch vehicle). One possible source for a launch window constraint is the specification of the initial longitude of the ascending node to satisfy special scientific objectives, such as observing specific astronomy targets within the first few days of operation. Such a nodal specification is likely to have sufficient tolerances so that no launch window problems will occur.

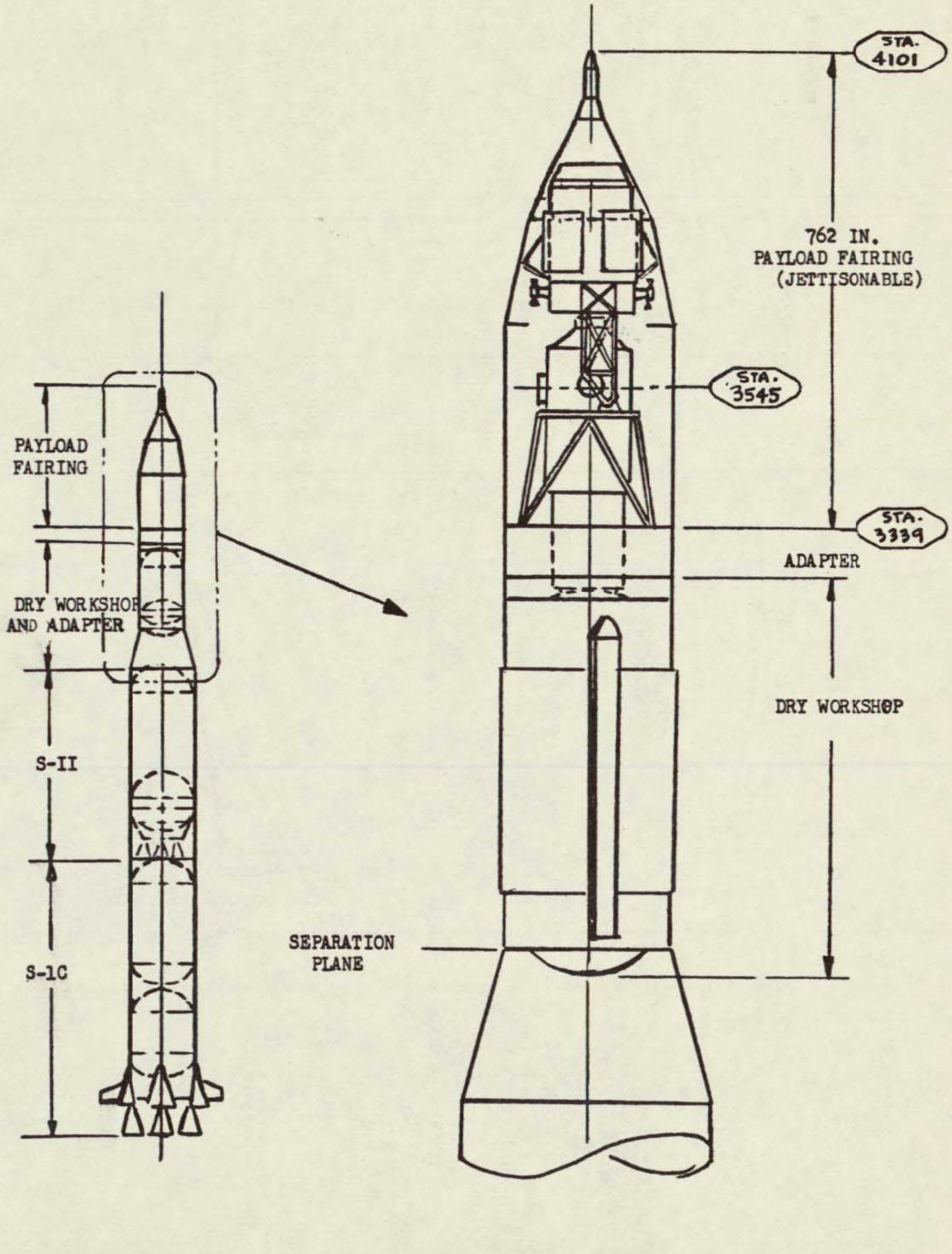


Fig. 6 Launch Configuration, AAP Cluster/LTEP

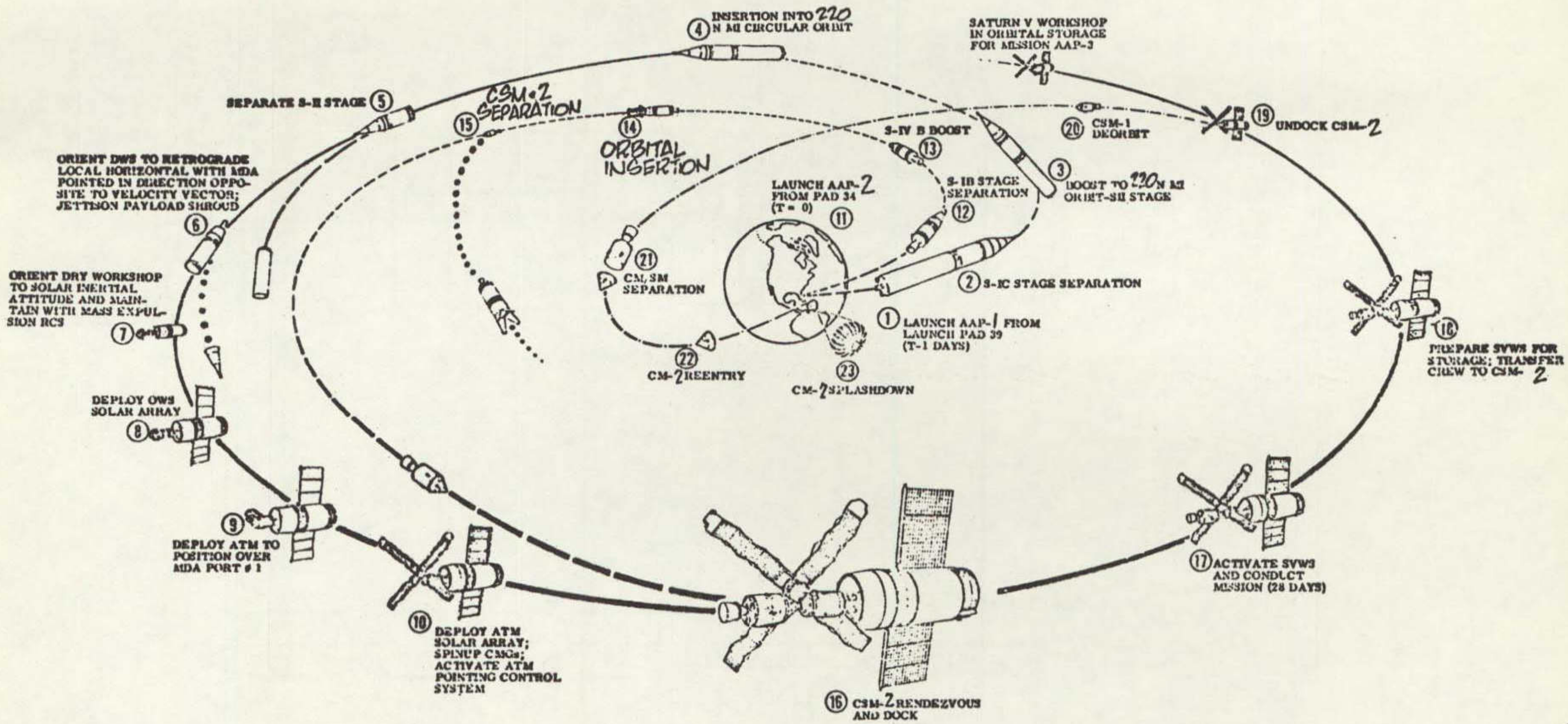


Fig. 7 Launch and Orbit Sequence of Events for Dry Workshop Cluster

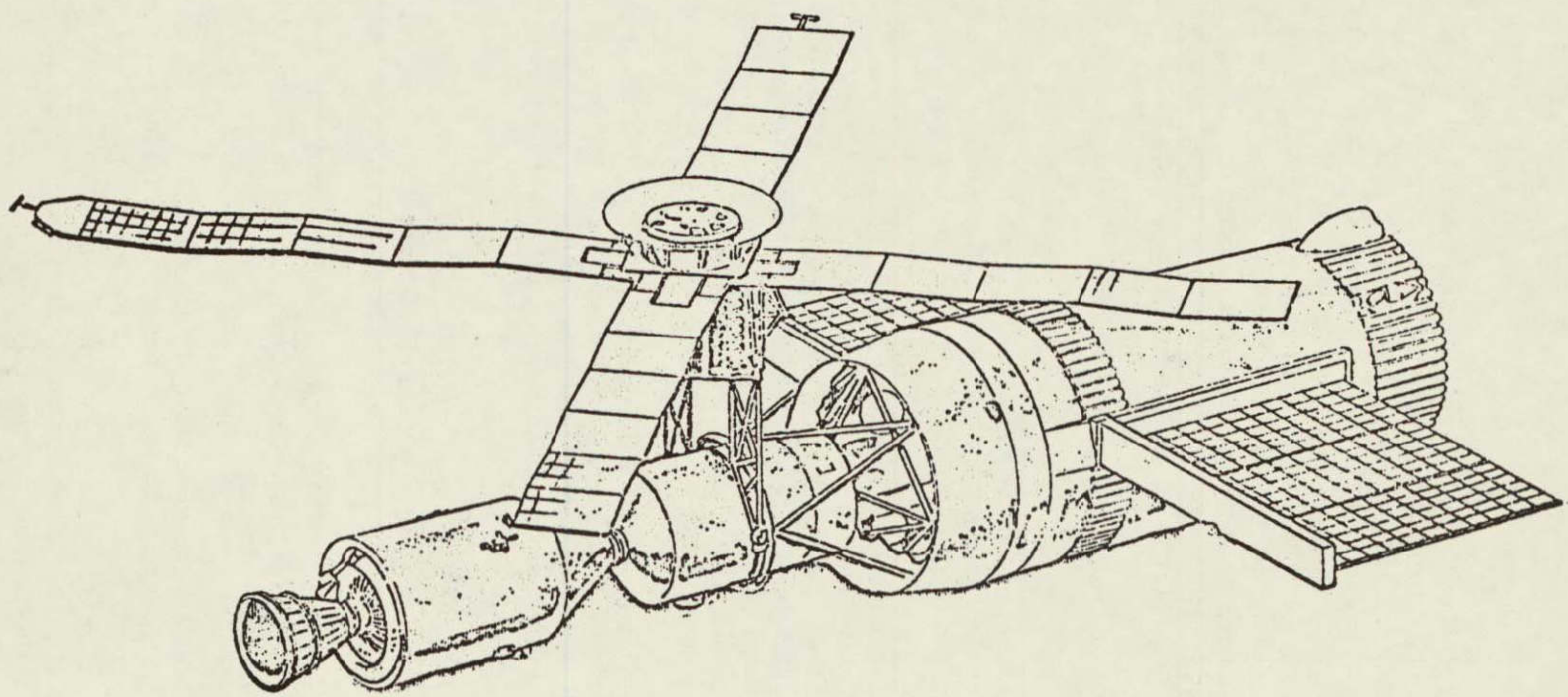


Fig. 8 Orbiting Configuration of AAP Dry Workshop Cluster (With Solar Telescope)

2.3.4 Cluster-Attached Operations

On the Saturn V launch, the ATM Rack will be attached rigidly to the two swing links. All g loads will be carried through the telescope structure to the mounting interface on the ATM Rack inner gimbal ring. The primary launch loads will be axial-aft, approximately 6 g maximum. The current ATM Rack flexural pivots, providing the gimbal ring supports and hinge points, are designed to support the weight of the ATM spar and experiment, approximately 5535 lb; the weight of the LTEP telescope (gimballed mass) is about 8100 lb. The pivot pin for the Launch Lock is mounted to the telescope girth ring. Adjustable snubbers bear against friction pads on the gimbal and roll rings (to damp launch vibrations) and retraction of the links is caused by two heavy clock springs after the pins are pulled. (The general arrangement of gimbal rings and launch locks is shown in paragraph 3.2.2.) The flexural pivot capability, both in launch loading and reaction in zero-g with the higher moments of inertia should be examined carefully in a follow-on study.

Figure 9 is an illustration of the Cluster/LTEP in orbit. The Thruster Attitude Control System (TACS) of the Cluster, located at the aft end of the Workshop (SIVB), will orient the total mass in a coarse-pointing mode to a star field. The CMGs and Experiment Pointing Control system (in the ATM Rack) will inertially maintain the selected position in space and provide fine-pointing (via the ATM gimbals) of the gimballed telescope. Commands will be sent to and data received from the LTEP Module via hardline connection into the MDA. During the continuous stellar-viewing periods, astronaut activity in the Cluster must be at a minimum to prevent disturbances reaching the telescope and causing beyond-limit oscillations.

2.3.5 Remote Operation

At some point in the total mission of the AAP Cluster, probably at completion of the Cluster operating period (approximately 270 days) the LTEP Module will be released from the Cluster and assume an independent or detached flight mode. The following potential operational modes (or combination thereof) must be accommodated by the LTEP system:

a. Station-Keeping with Manned Cluster. The LTEP module will be released during Cluster crew activity period. Operation will be monitored by the Cluster. Commands will be provided by Cluster or Ground Control.

b. Free-Flight. The LTEP Module will be released at the end of the manned occupancy period of Cluster operation. It will then operate independently with ground-command link only.

At the point of LTEP Module release from the Cluster, the Cluster will lose its inertial platform capability (CMGs are mounted on the modified ATM rack, which are part of the LTEP Module). The Cluster can maintain its orbital position and maneuver, using its Thruster Attitude Control System. The need for partially-redundant flight control electronics within the Cluster must be investigated if the LTEP Module is released prior to completion of the Cluster overall mission.

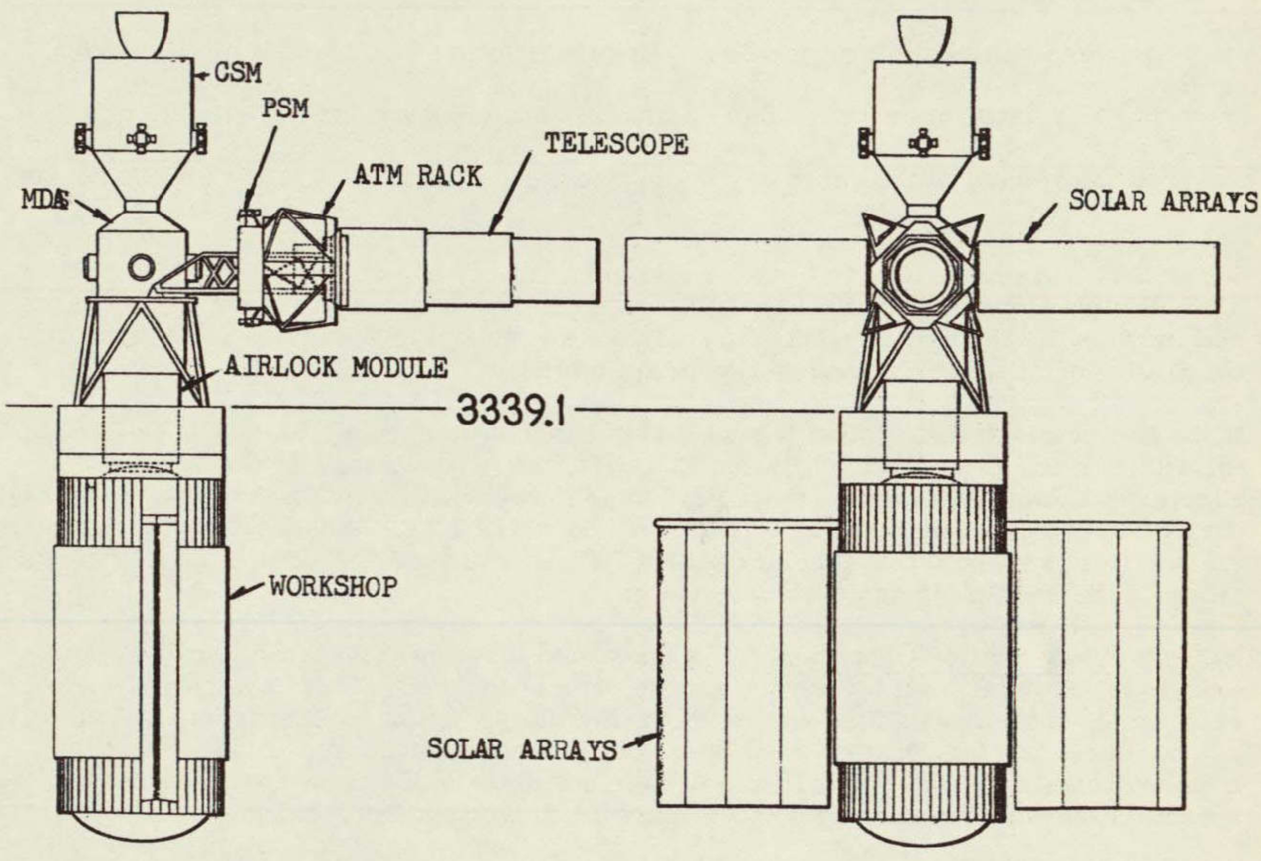


Fig. 9 Orbit Configuration of Cluster/LTEP

2.3.6 Space Shuttle/Space Station Alternate

The aforementioned LTEP Module (comprising Propulsion/Support Module, ATM Rack, Solar Arrays, and Telescope Assembly) can also operate attached to, or in station-keeping with, the proposed Space Shuttle or Space Station.

2.3.6.1 Space Shuttle Installation. The Space Shuttle has adequate volume in its cargo bay to stow the LTEP Module. Figure 10 illustrates the comparative dimensions. Presuming that cargo-bay doors can be opened in space for the 40 ft long segment of the cargo bay, the LTEP Module would be supported rigidly during ascent on a truss-frame within the cargo bay and when in orbit:

a. Rotated to "aiming" position, using the Shuttle as an inertial platform, or

b. Moved out of the cargo bay by linkages and deployed for free-flight, or

c. Moved out of the cargo bay by linkages and attached to a Space Station docking port.

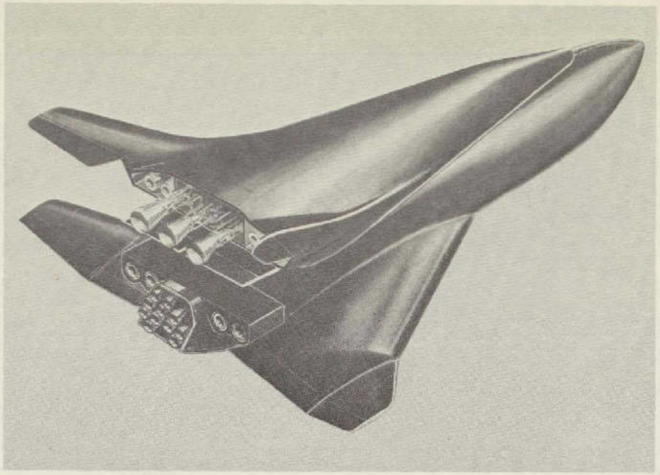
Using the Shuttle as an inertial platform would probably negate the use of the CMGs as a stabilizing device for the Shuttle/LTEP combination (because of the very large mass and inertias of the Shuttle). Further analysis is required of this mode at such time as the Shuttle orbit flight characteristics are established.

If the Shuttle electrical system has sufficient capacity to support the LTEP Module in the attached operating mode, between 1350 watts and 1700 watts (see Section 3.4.3, Electrical Power Subsystem), the LTEP solar arrays could remain stowed and dormant during the Shuttle-captive period. If free-flight of the LTEP Module were not planned, the solar arrays could possibly be omitted. Further analysis is needed upon firm definition of the Shuttle electrical power system.

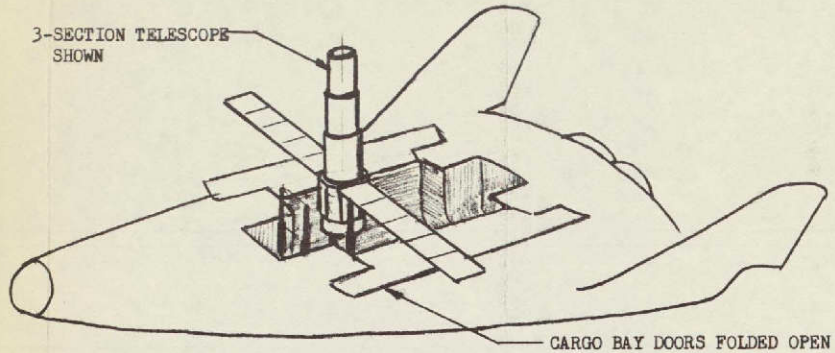
2.3.6.2 Space Station Operation. It is presumed that the LTEP Module can be delivered to the Space Station by a Space Shuttle vehicle. The LTEP Module can be mechanically attached to a Space Station port by the Shuttle or, after release from the Shuttle, can be "flown in" for docking to the Space Station by combination of rendezvous electronics aboard the LTEP Module and RF commands from the crew control panel in the Space Station near the docking port. Figure 11 illustrates the docking configuration.

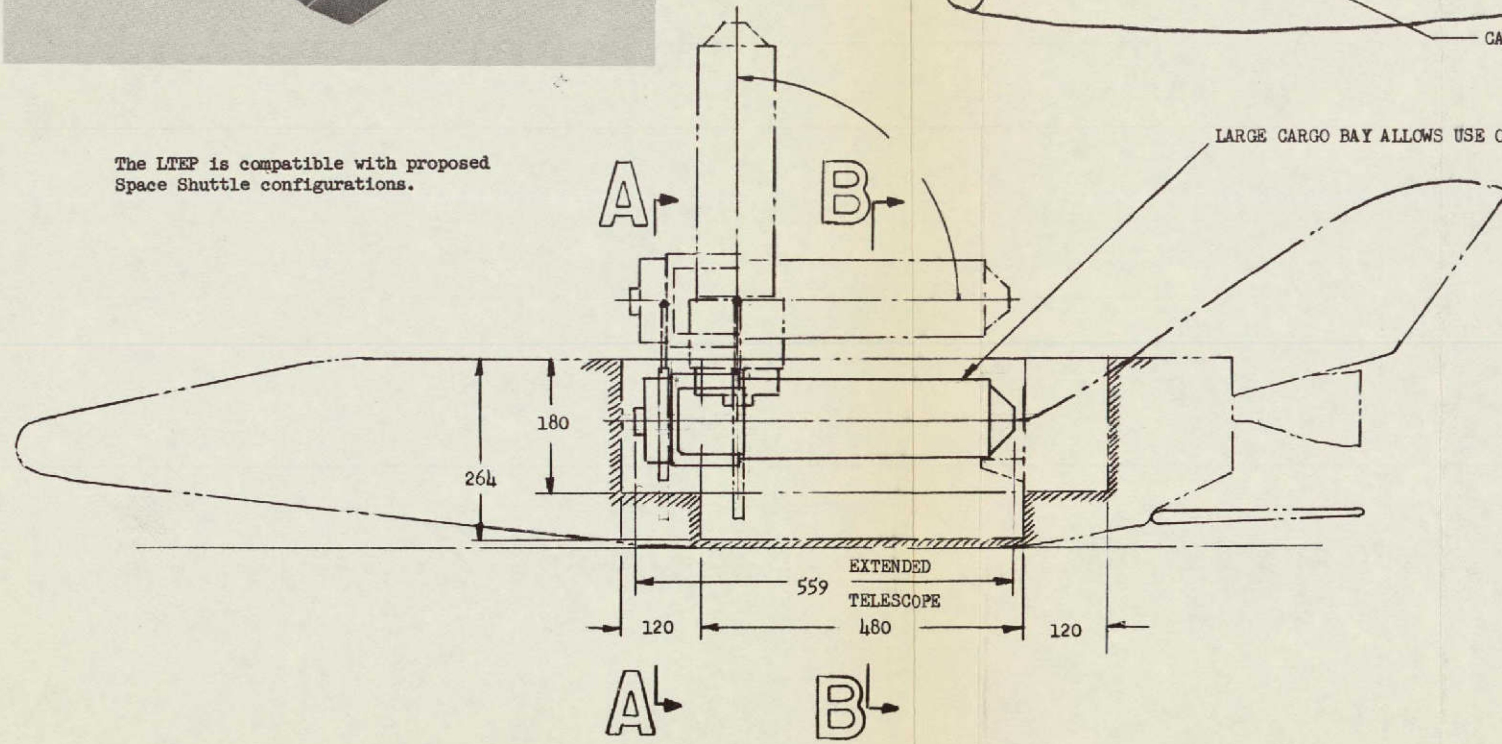
Here again the LTEP CMGs will probably be ineffective in inertially holding the space station in a stellar-pointing position. It has been tentatively assumed that the space station control system will provide coarse-pointing and stabilization within limits compatible with the LTEP system fine-pointing capability. The existing ATM gimballing system could be used if this were the case (the CMGs would be omitted if later free-flight were not planned).

If the total Station/LTEP combination were inertially fixed and stellar-pointing, movable solar arrays would be required on the Station to sustain electrical loads for the long pointing periods (several hours to 4 days). This case will require further analysis when the electrical power system for the Space Station is firmly defined.



The LTEP is compatible with proposed Space Shuttle configurations.





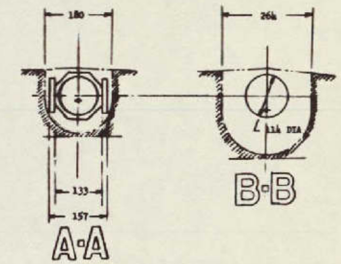


Fig. 10 LTEP Module Installation in Space Shuttle

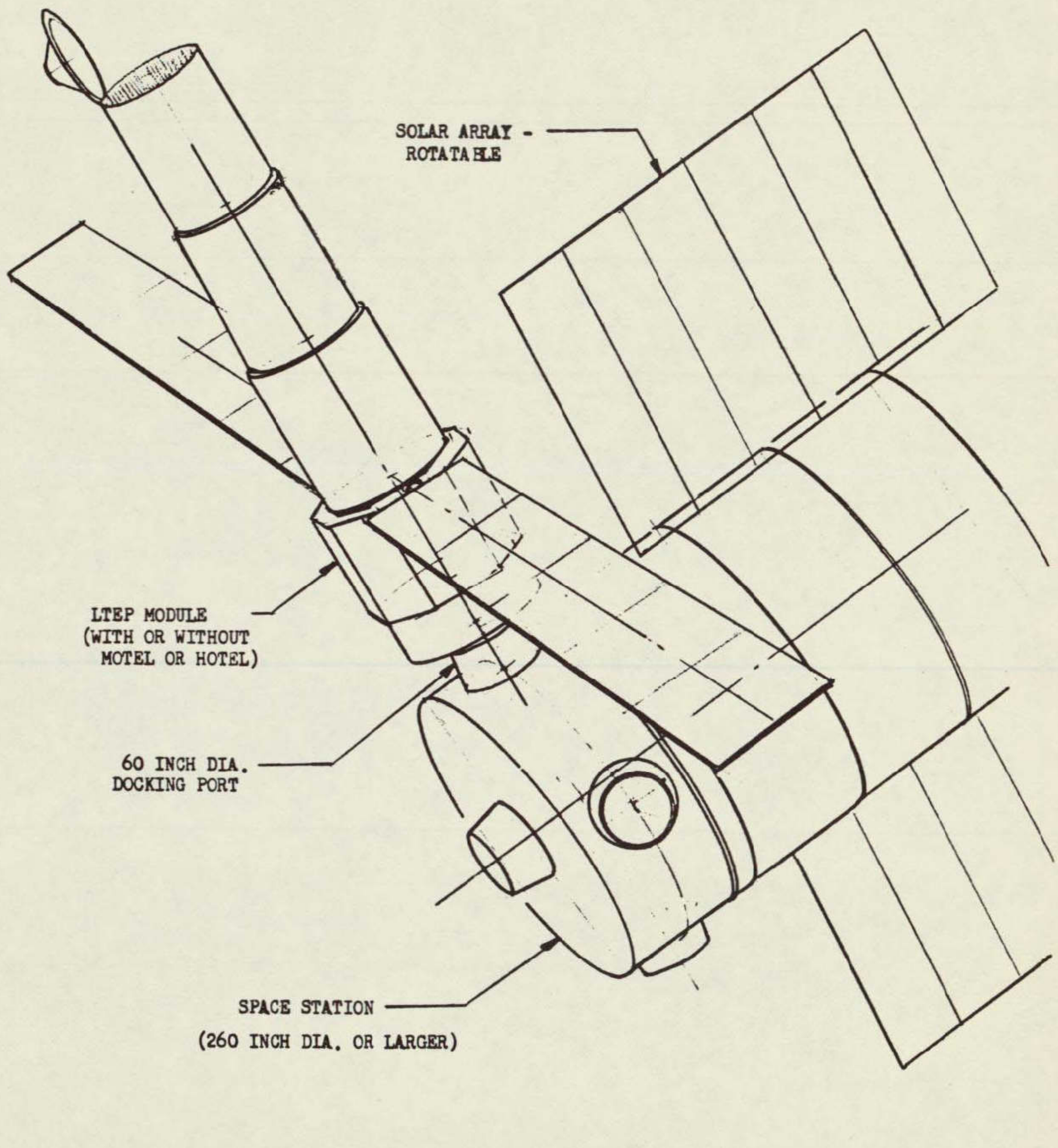


Fig. 11 LTEP Module Docked to Space Station

Section 3

LTEP BASELINE SPACECRAFT SYSTEM

In this section, the LTEP Module is described, the launch and orbit-erection procedures are defined, and the subsystem characteristics and development problems are outlined. The characteristics of the system are tabularized at the end of the section, i.e., paragraph 3.5, Configuration Summary.

3.1 OVERALL LTEP MODULE CONFIGURATION

Figure 12 is an illustration of the LTEP Module. The four basic elements and sub-elements thereof are:

Telescope Assembly. Comprises a 3-section tube, an electro-optical equipment compartment, a C.G. positioner, and experiments. Further description of the structural components is contained in Section 3.4.1. The erection devices are discussed in Section 3.3.1

ATM Rack (Modified). The Telescope Assembly mounts into the gimbal rings of the ATM Rack. The inertial-platform components, three large Control Moment Gyros (CMGs) and associated electronics, the batteries and controls of the electrical power subsystem, and the gimbal fine-pointing control system are mounted on the Rack structure. More detail is provided in Section 3.3.3.

Solar Arrays. Two of the four ATM solar array wings are mounted on the ATM Rack (not shown on the figure). They are rotatable about a single hinge axis. A description of the arrays and the electrical power subsystem is contained in Section 3.4.3.

Propulsion/Support Module. A cylindrical module attaches rigidly to the end bulkhead of the ATM Rack. This sheetmetal structure contains the remaining supporting subsystems for the LTEP System:

- Axial and Attitude Control Thrusters
- Attitude Control Subsystem
- Propulsion Subsystem
- Auxiliary Electrical Power Subsystem
- Communications and Instrumentation Subsystem

Figure 13 shows the primary dimensional characteristics of the LTEP Module. The extended overall length is 559 inches. The stowed overall length is 334 inches.

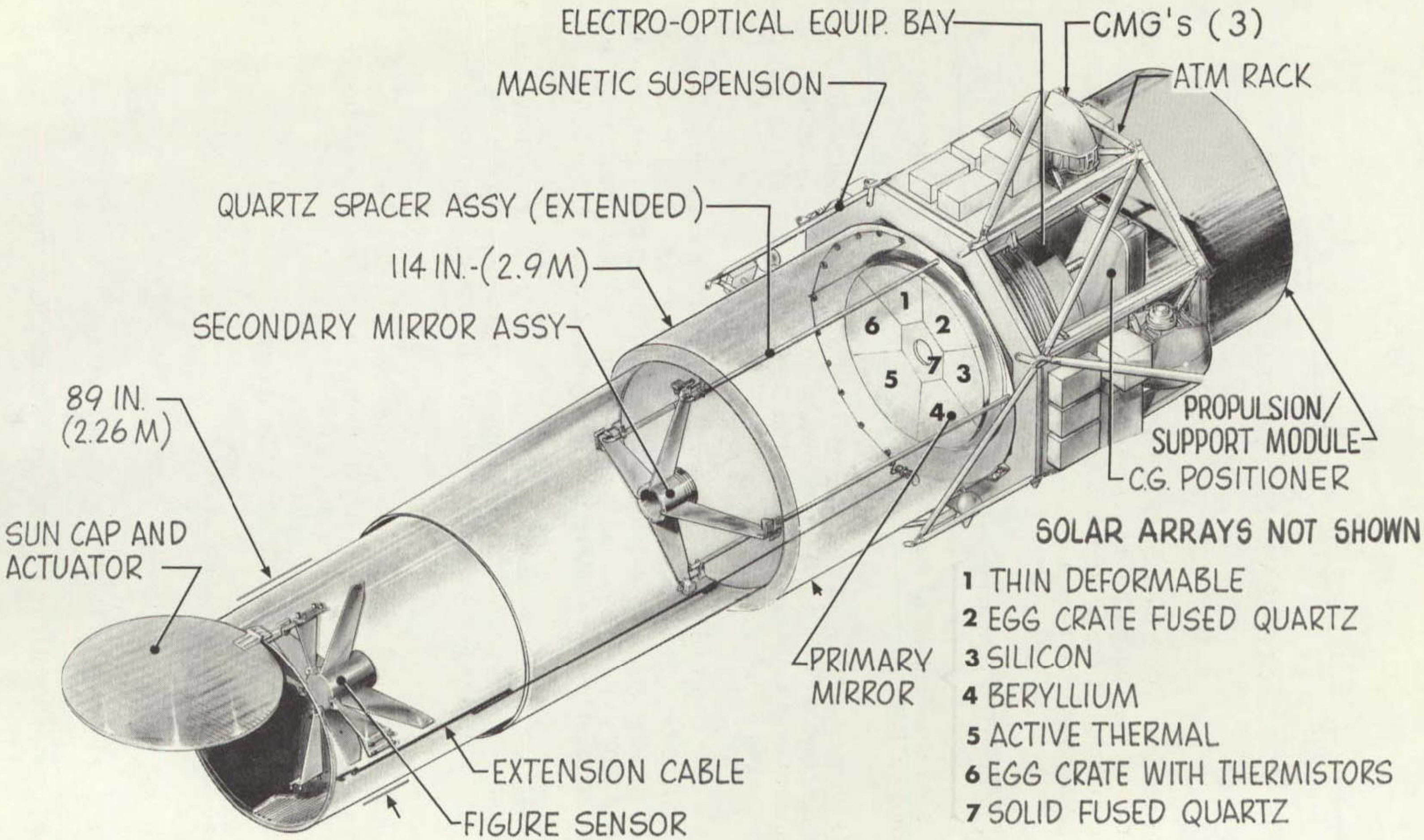


Fig. 12 Overall Configuration of LTEP Module

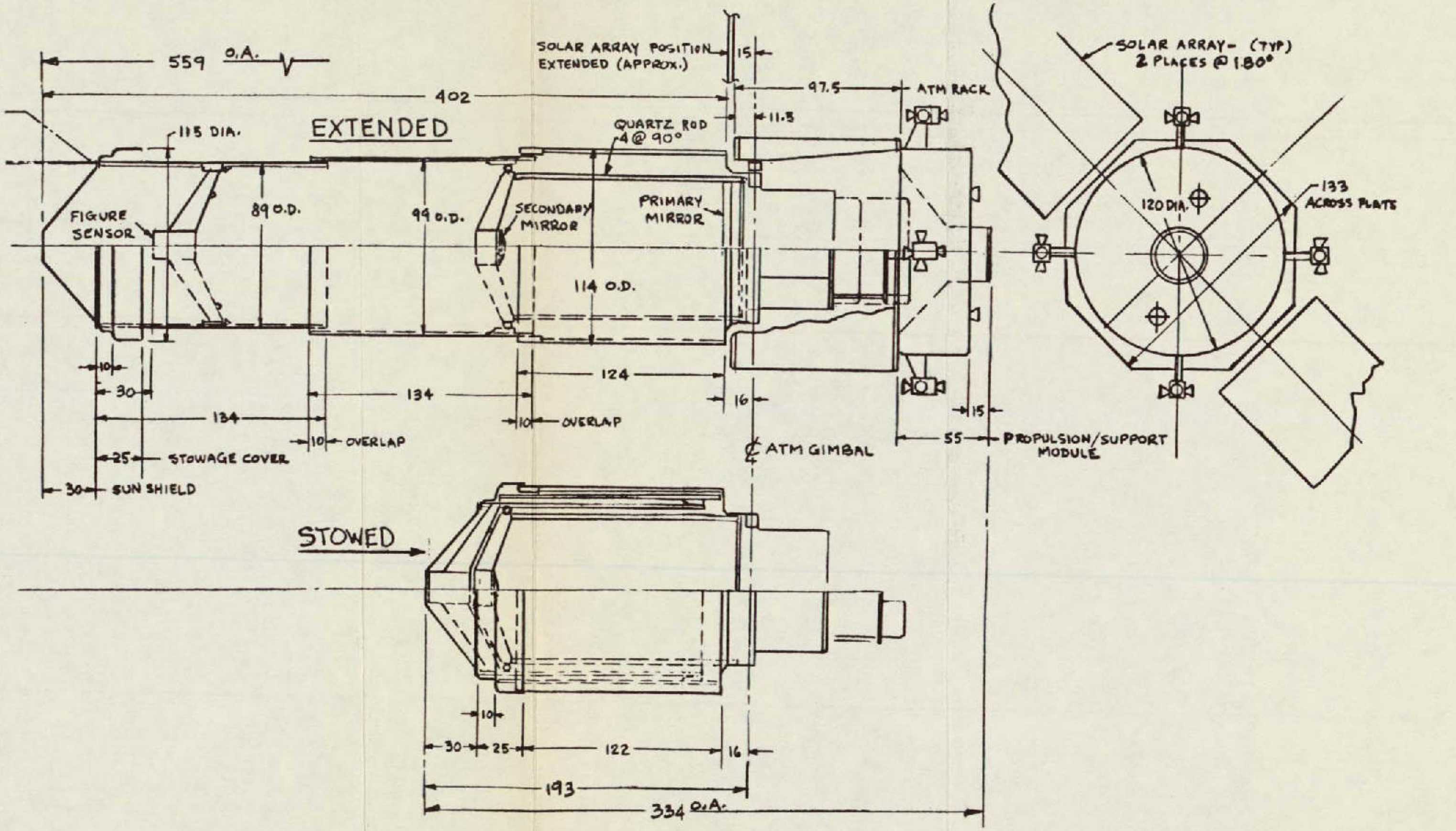


Fig. 13 LTEP Arrangements, Launch-Stowed and Orbit

FOLDOUT FRAME 1

FOLDOUT FRAME 2

3.2 LAUNCH, ASCENT, AND ERECTION

The launch configuration within the Payload Fairing is shown, the launch protection arrangement is described, and the LTEP system sequence of events is provided.

3.2.1 Saturn Payload Enclosure

The new Dry Workshop launch arrangement, recently adopted by NASA, is illustrated in Fig. 14. The mass of the ATM Rack, the Solar Arrays (4), and the Solar Telescope is supported by the ATM swing links and truss-frame support. The weights of these elements are:

Rack	9232 lb
Solar Arrays	4070
Spar and Experiment (Telescope)	5535
Total	18,837 lb

The payload fairing encloses the truss-frame support and the ATM payload. The critical clearance between the fairing and the payload occurs with the fixed sun shade (mounted atop the ATM Rack).

Figure 15 illustrates the LTEP Module mounted on the Dry Workshop swing links with a nominal 5-inch clearance between the adjacent docking ports of the MDA and the LTEP Propulsion/Support Module. The Dry Workshop payload fairing will enclose this payload arrangement but with a fairly close fit between the forward cone of the fairing and the LTEP telescope caging structure. If this arrangement is implemented, snubber blocks of resilient material should be placed between the fairing and the caging structure, slightly compressed to prevent "bumping" during launch and ascent vibration and deflection conditions. A similar close-fit exists between the folded solar arrays and the fairing. Detail clearance layouts of these areas are required as the Saturn Dry Workshop fairing design is firmed up and when the LTEP specific configuration has been selected.

Figure 16 illustrates the recommended 3-section telescope and ATM Rack combination (without the Propulsion/Support Module) fitted within the payload fairing. Here again the minimal clearance between the stowed telescope envelope and the fairing would require addition of snubber blocks to prevent destructive bumping during launch and ascent. Although this particular configuration has not been discussed, it is feasible if the LTEP system is never to be released from the cluster (certain LTEP-peculiar data processing packages could be mounted on the ATM Rack).

To provide sufficient clearance for the complete LTEP Module with the 3-section telescope, the 762-inch long payload fairing must be moved away from the SIVB interface at Sta. 3339.095 approximately 55 inches (as shown in Fig. 17) . A simple cylindrical adapter can be added. This is the preferred launch configuration for the LTEP system, allowing both a versatile LTEP Module and providing a simple payload fairing interface

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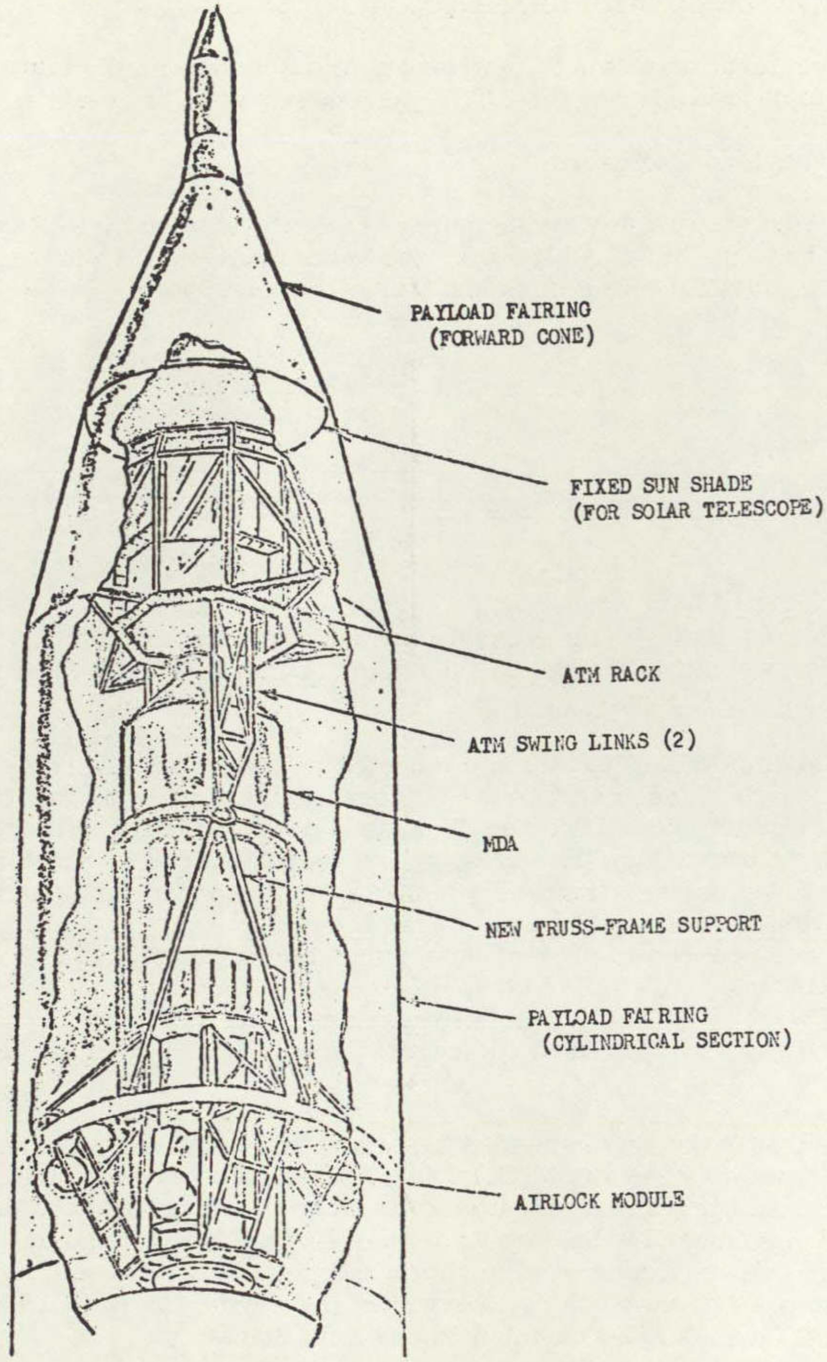


Fig. 14 Dry Workshop Launch Configuration (With Solar Telescope)

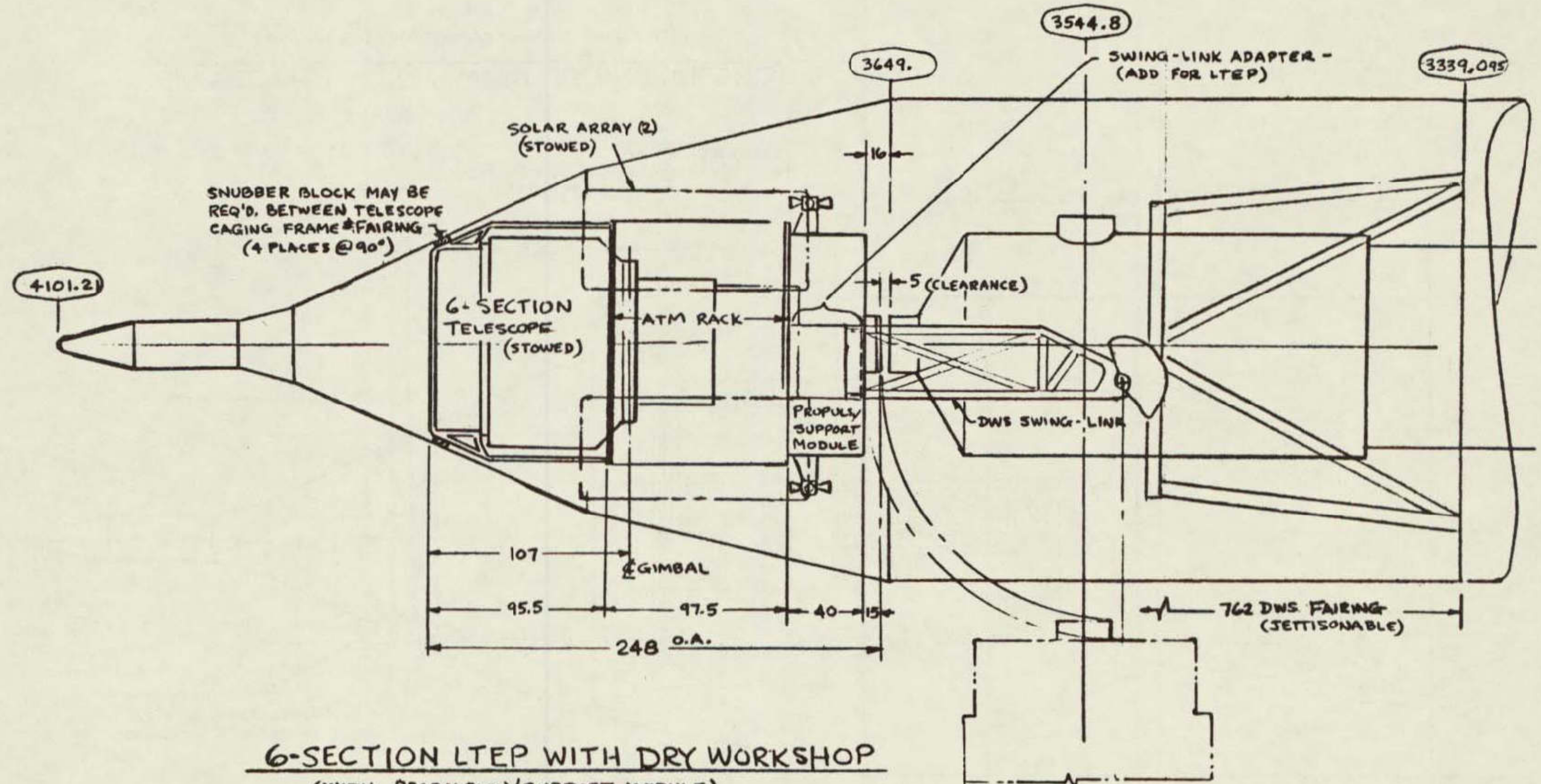


Fig. 15 6-Section LTEP Module With Dry Workshop

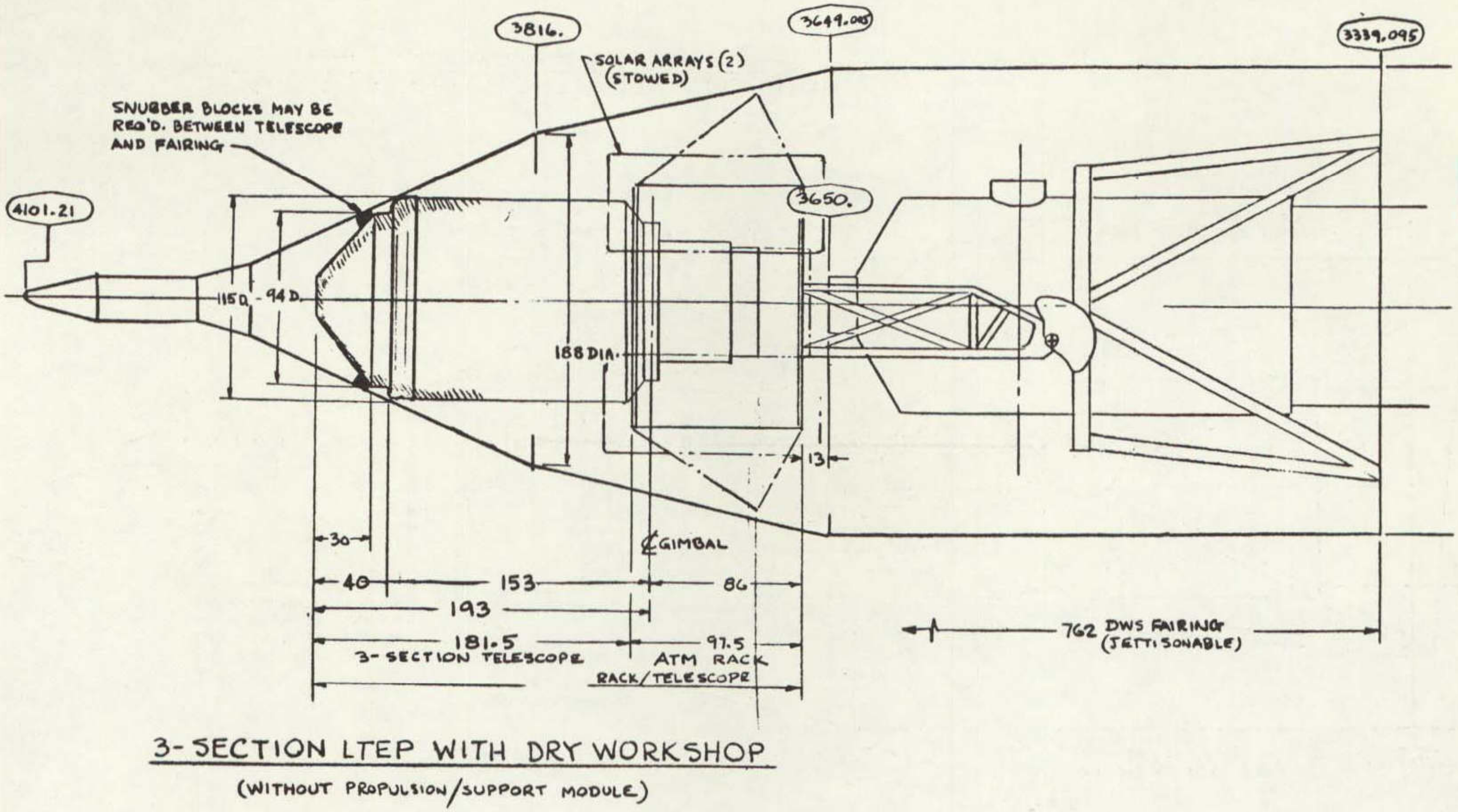
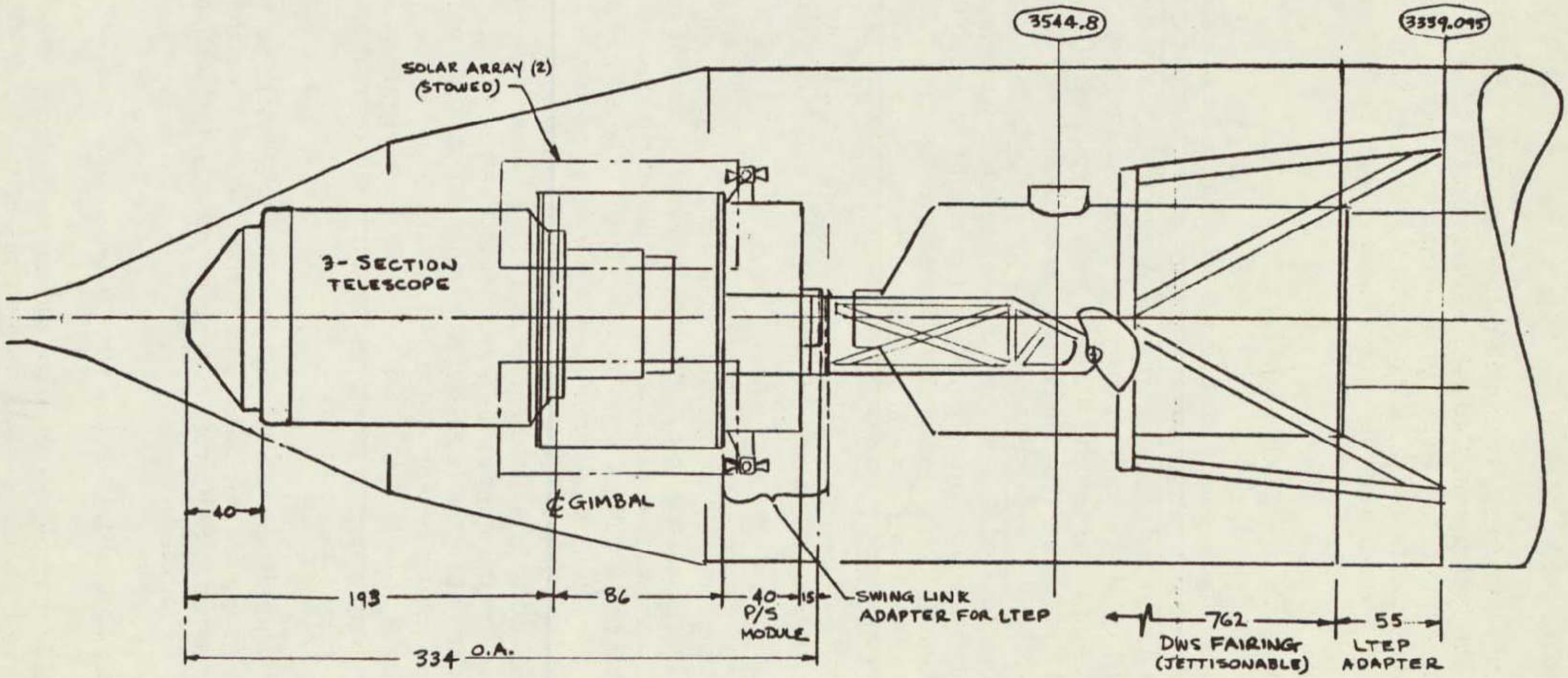


Fig. 16 3-Section LTEP (Without PSM) With Dry Workshop



3-SECTION 2 METER LTEP WITH DRY WORKSHOP
(WITH PROPULSION/SUPPORT MODULE)

Fig. 17 3-Section LTEP Module With Dry Workshop with other Dry Workshop launches. It is understood that NASA/MSFC currently plans an adapter forward of the Instrument Unit (IU) section on the SIVB. If this adapter, when Dry Workshop dimensions are firm, is 55 or more inches in length, a duplicate can be added for the aforementioned LTEP payload fairing requirement. This approach, as illustrated in Fig. 17, constitutes the recommended concept for implementation of the LTEP system.

3.2.2 Overall Launch Concept – Caging System

As mentioned previously, the 6-section telescope was the point of departure for the current study. With the objectives of simplification and rigidization, the 3-section telescope concept was developed. A primary advantage of this new concept is the rigid, one-piece quartz rods (set of 4) which support the secondary mirror frame (in the 6-section telescope, hinging and folding of these rods is required for the launch-stowed condition). Figure 18 illustrates the launch-stowed configuration of the LTEP 3-section telescope. Figure 19 provides preliminary drawings of the launch locks being built for the ATM. (Although two configurations for the pyrotechnically actuated pin pullers are shown, the side-mounted versions illustrated on the right are presently planned for use.) The pivot pin for the launch lock is mounted to the telescope girth ring. Adjustable snubbers bear against friction pads on the gimbal and roll rings (to damp launch vibrations) and retraction of the links is caused by two heavy clock springs after the pins are pulled. The general arrangement of gimbal rings and launch locks is shown in Fig. 20 for the ATM Experiment Pointing Control (EPC) and Roll Positioning Mechanism (RPM).

In the proposed 3-section stowed arrangement, shown in Fig. 18, the lower fixed section of the telescope functions as a "box" in which is located the two extendable sections. The "lid" of the box is a stowage cover and the sun shield; the cover is attached permanently to the end ring of the smallest telescope section. The shield is hinged on one side and secured with a latch located opposite (at 180 deg). A lower retainer ring is provided on the base of the fixed section to restrain the retracted telescope sections from lateral movement and to sustain aft loading during launch and ascent. The stowage cover rests against the top ring of the intermediate telescope section and is attached to the fixed section at two points (180 deg opposed) with pin puller devices (pyrotechnic actuation). The figure sensor support frame is keyed to the secondary mirror frame (one cone-point pin in each of the four webs) to prevent lateral movement of the secondary mirror (the figure sensor frame webs will react lateral loads directly into the smallest-diameter telescope section).

Upon attainment of orbit position, the stowage cover latches will be released, the telescope sections extended (see Section 3.3.1 for description of erection mechanism) and the sun shield latch released. Following coarse-pointing stabilization, the ATM gimbal caging frames will be disengaged.

3.2.3 Launch, Ascent, and Initial Orbital Operation

The LTEP Module will be completely checked out in the Vehicle Assembly Building prior to movement to the launch pad. All subsystems of the LTEP Module will be dormant during the prelaunch countdown except for monitoring a few temperature and pressure transducers. These data will be transmitted via hardline into the cluster

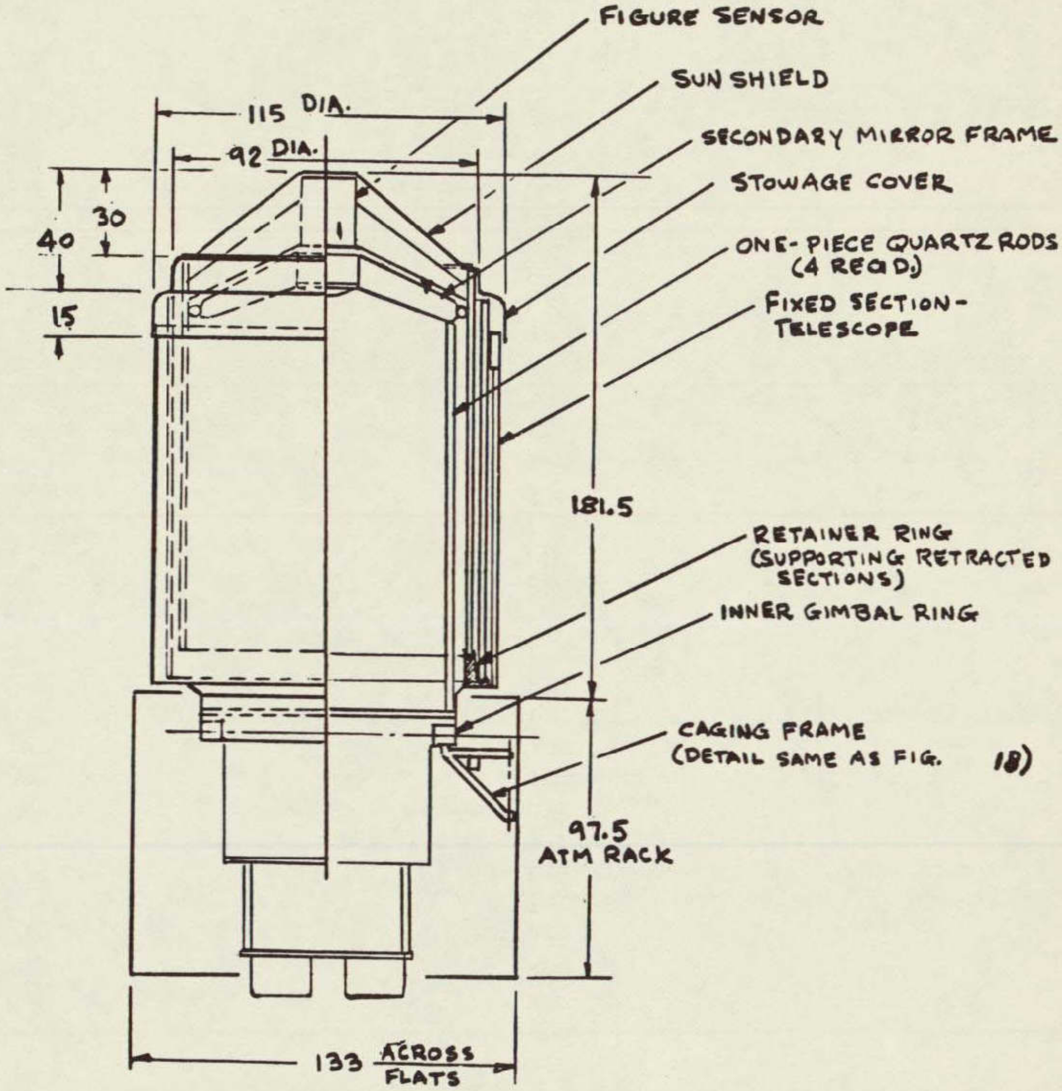


Fig. 18 Launch Caging Arrangement for 3-Section Telescope

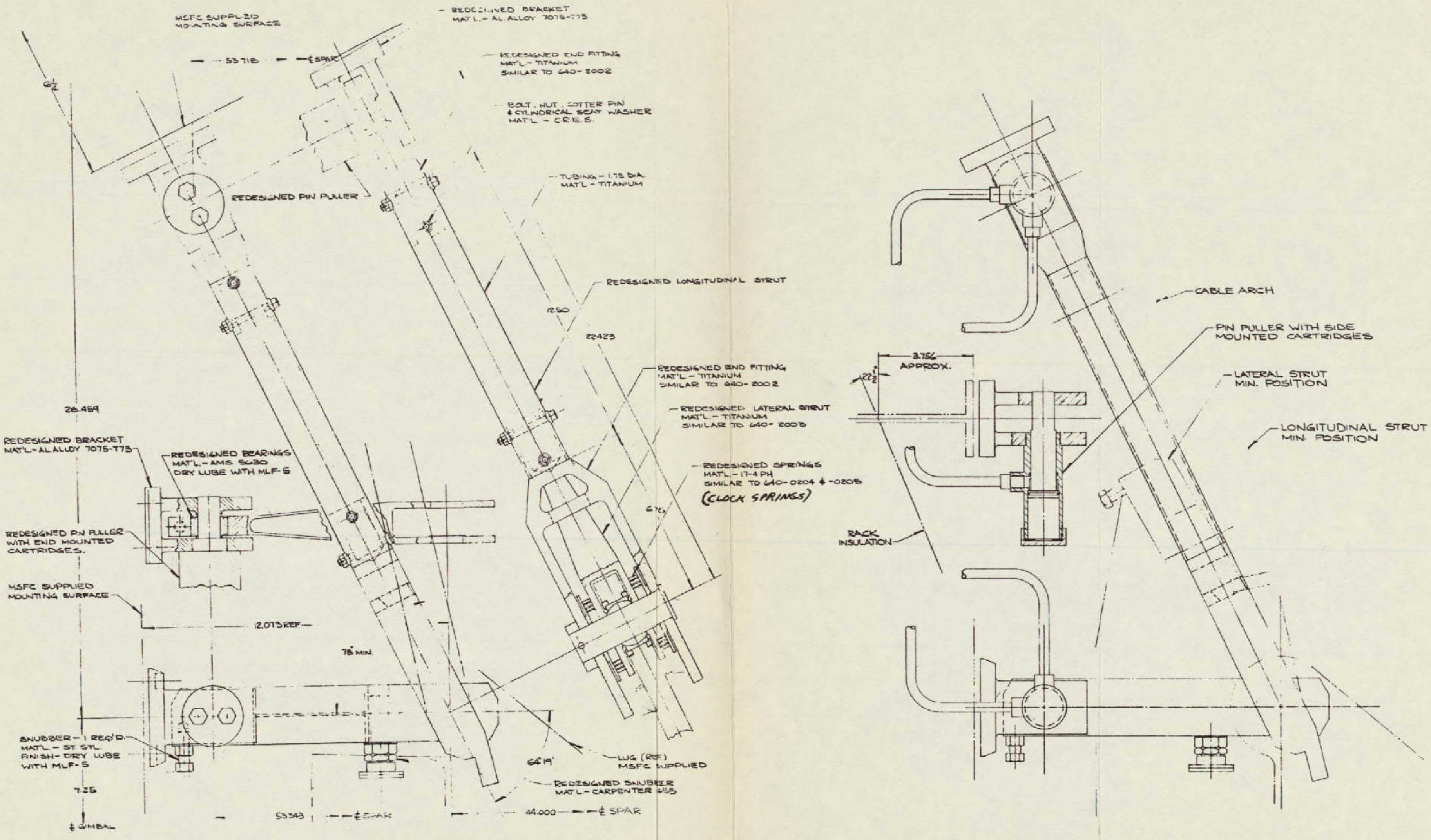


Fig. 19 ATM, Proposed Launch Lock

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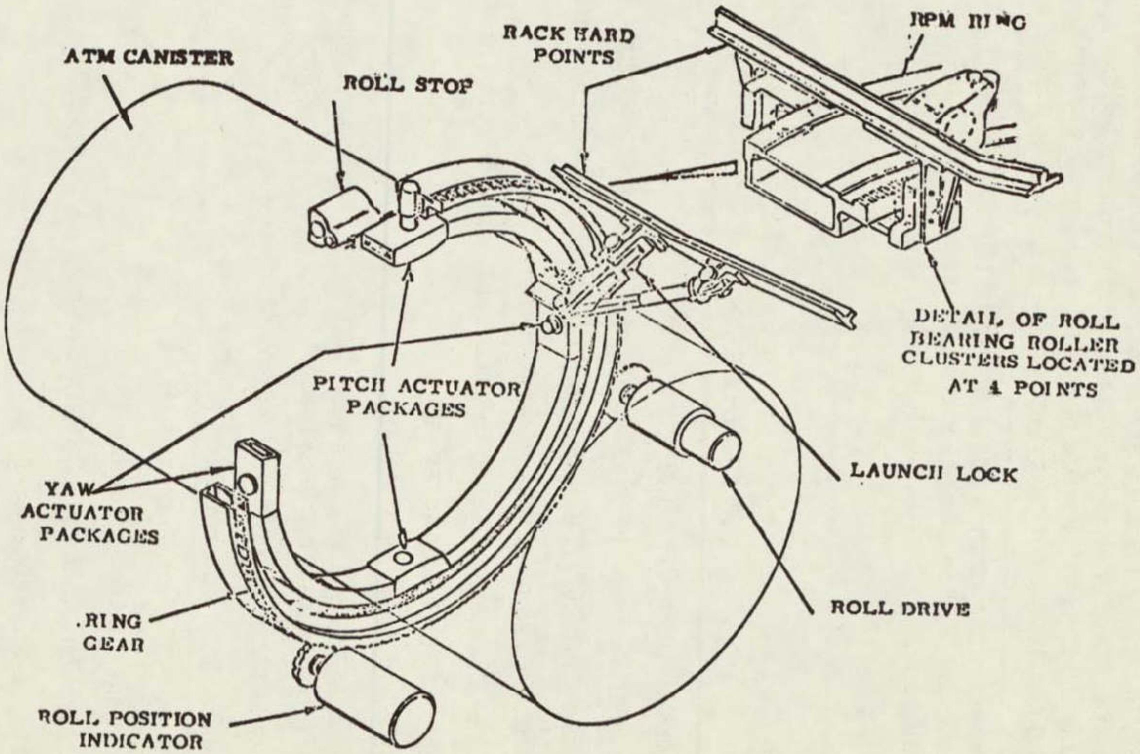


Fig. 20 Arrangement of ATM and RPM

and combined with other data going to ground control via the main Cluster launch umbilical. Air conditioning (via ducting) will probably be supplied to the interior of the payload fairing for temperature control of Cluster elements. This forced-ventilation cooling will be adequate for the LTEP Module.

Ground communications will be provided by the launch vehicle (SIC/SII) and the Dry Workshop (SIVB) during launch and ascent; all commands to the LTEP Module will be via S-Band to the Cluster Instrumentation and Communications and then hardline via the MDA to the LTEP Module (see Section 3.4.5 for a description of the LTEP Communication and Instrumentation Subsystem).

Table 1 provides a list of the operations initiated by pre-programmed timers and/or by ground command. The sequence starts with separation of the Cluster/LTEP from the SII booster stage and ends with the telescope ready for steady-state pointing to a stellar target.

Table 1

LAUNCH, ASCENT, ORBIT ERECTION SEQUENCE OF EVENTS – AAP CLUSTER AND LTEP MODULE

- Separate from the SII stage
- Fire SII stage retro-rockets (to obtain separation with Cluster/LTEP)
- Rotate Cluster/LTEP 180 deg to point payload fairing aft
- Jettison payload fairing (one-piece)
- Orient Cluster/LTEP to inertial orbit attitude (cluster attitude control)
- Deploy DWS solar arrays (2)
- Unlock ATM swing links (2)
- Rotate ATM Swing Links (and LTEP) 90 deg from Launch Position (motor on Cluster truss-frame)
- Lock ATM swing links in extended position
- Unlock ATM solar arrays (4)
- Deploy ATM solar arrays (4)
- Spin-up Control Moment Gyros
- Rendezvous and dock CSM in forward port on MDA
- Release telescope tube lock (stowed position)
- Extend telescope tube
- Lock telescope tube in extended position (at 2 ring positions)
- Activate ATM Experiment pointing control system
- Uncage ATM gimbals
- Activate LTEP optical control system
- Open sunshield

3.3 PROGRAM-PECULIAR ELEMENTS

Special elements required for the LTEP system operation with the AAP Cluster, exclusive of the subsystems described in Section 3.4, are the telescope erection mechanism, the Propulsion/Support Module, the modified ATM Rack, and the rotating devices for the ATM solar arrays and for the Workshop solar arrays. The conceptual design of these elements is described in the following paragraphs.

3.3.1 Erection Mechanisms and Extend-Locks

The screw-jack extension mechanism for the 3-section telescope is illustrated in Fig. 21. It embodies the following operating features:

Interconnected Drive Motors. A drive motor with appropriate gearing is provided for each screw-jack. The motors are slip-clutched so that if a motor fails, the gear train can be driven by the other motors via the interconnecting flex shafts. Gear ratios will be established so that a single motor will have sufficient power to extend the telescope sections; this will afford a very high degree of reliability. The interconnected gear boxes also assure synchronized extension of each jack.

Manual Crank. It is possible that a manual crank can be installed on at least two of the four motor gear boxes to afford hand-cranking by an astronaut as a backup mode for telescope extension.

Screw-Jacks. The screw-jacks will be of the ball-screw or tapered-roller/acme screw types to provide minimum friction and zero-slip fit. The screw which extends the inner tube section will be provided a free running fit inside the larger screw which extends the middle section (relative to the lower fixed section). The inner screw is fixed in rotation (pinned to the upper support); the outer screw will rotate counter to the threaded journal which is raising the inner screw, thereby providing simultaneous extension of both sections.

Downlock. The screw-jacks in the retracted position can be used to restrain the stowage cover in the down (and locked) position. Use of very low thread pitch on the screw to obtain irreversibility may allow elimination of the stowage cover downlocks (2) and reduce the number of series-sequence events for erecting the telescope.

Uplock. The use of the screw-jacks to hold the telescope in the extended position may also be feasible. Irreversible screws combined with overdrive-position compression springs on the end of each screw would allow the sections to be extended against "stop" blocks (for precision extended position) and held in tension by the override compression springs.

Structural Support. The screw-jacks can be made reasonably strong for cantilever bending loads without significant weight increase and in the extended and preloaded condition possibly can sustain the small loads on the telescope sections resulting from angular accelerations. This potentially would allow reduction of the tube skin thicknesses. Detailed analysis of this structural loading concept should be accomplished as part of the Phase B studies.

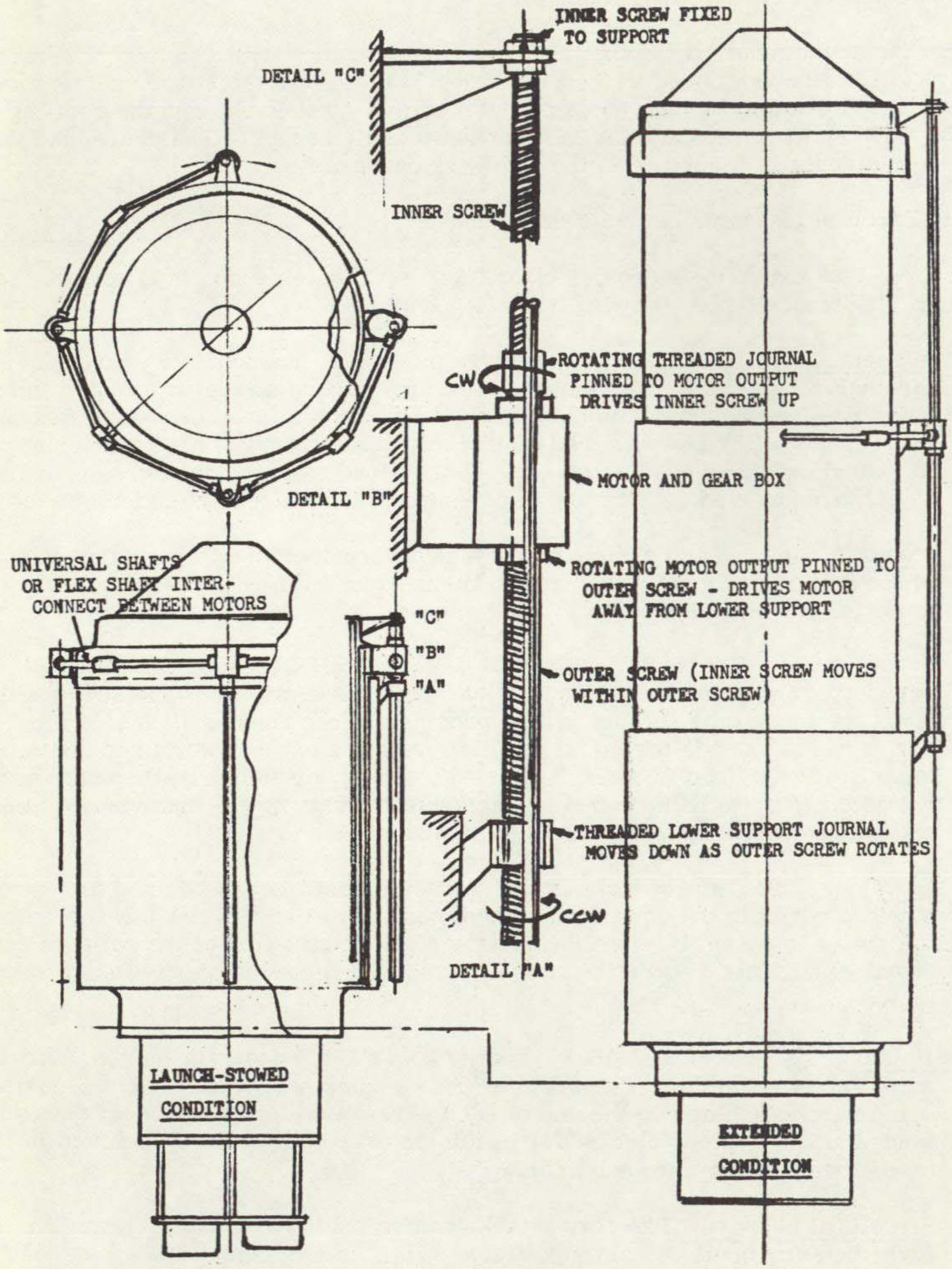


Fig. 21 Screw-jack Telescope Extension Concept

An alternate extension system is shown in Fig. 22. It was developed initially for the 6-section telescope but the concept can be applied to the 3-section configuration. This design comprises a motor and cable-winch which winds up a cable; shortening of the cable "pulls" each section out of its stowed position until all sections are extended and wedge-locked in that position. Multiple cable systems, at least three equally spaced around the circumference, are proposed with redundant motor drives on each system.

Mating wedge rings will be installed on the top of each outer section and on the bottom of the mating inner section as shown in Fig. 23. These rings, perhaps provided with stop blocks to precisely limit longitudinal extension of each tube section, when physically mated will provide girth-ring stiffening.

When the wedge rings reach the mated position, a position-indicator switch will activate pyrotechnic pin-drive devices peripherally mounted in the wedge ring cavity. A pair of pins on each device will be driven through the mating ring thicknesses, locking the two rings together. Six of these devices (2 pins per device) will be utilized for each tube joint and will be spaced at 60 deg about the tube circumference. There will be a total of 12 devices (2 joints) on the 3-section telescope. The reliability of this type of pyrotechnic-powered device is extremely high. Increased reliability will be attained by providing two separate chambers in the device with redundant propellant cartridges. Because of the contamination hazard, an expandable bladder-type enclosure will be used to trap all contaminants exhausted by the devices.

3.3.2 LTEP Propulsion and Support Module

Because one of the flight modes involves free-flight of the LTEP Module (separated from the Cluster), a full complement of support subsystems, including propulsion/attitude control, must be provided. Limited additional packaging space within the ATM Rack envelope and the objective of maintaining the minimum-diameter envelope were used as the basis for conceptual development of a versatile, but essentially simple, Propulsion/Support Module (PSM). The PSM will attach to the end octagonal bulkhead of the ATM Rack.

The basic configuration of the PSM is shown in Fig. 24. It is a 120-inch diameter cylinder 40 inches long with a 15-inch long docking tunnel/ring and outrigger struts at four places each supporting a cluster of attitude control thrusters. The features of the module are discussed following; details of the subsystems are described in Section 3.4. A weight breakdown of the PSM is included in Section 3.5.2.

<u>Basic Structure.</u> The structure comprises an outer cylindrical shell, an inner conical shell, four radial webs, and a docking tunnel assembly. Extensions of the webs externally support the thruster clusters. The structure is conventional riveted or welded aluminum alloy. Quick-open access doors will be provided in the cylindrical shell to allow direct access to the equipment compartments by astronauts performing in-orbit inspection and maintenance.

<u>Docking Provisions.</u> An Apollo docking ring and drogue cone will be mounted in the structural tunnel. This is a provision which has been added to allow docking of the manned Apollo CSM. An astronaut can gain access through this tunnel to the bottom end of the telescope without utilizing EVA; this may afford reasonably simple removal of data packages from the telescope experiment/equipment compartments.

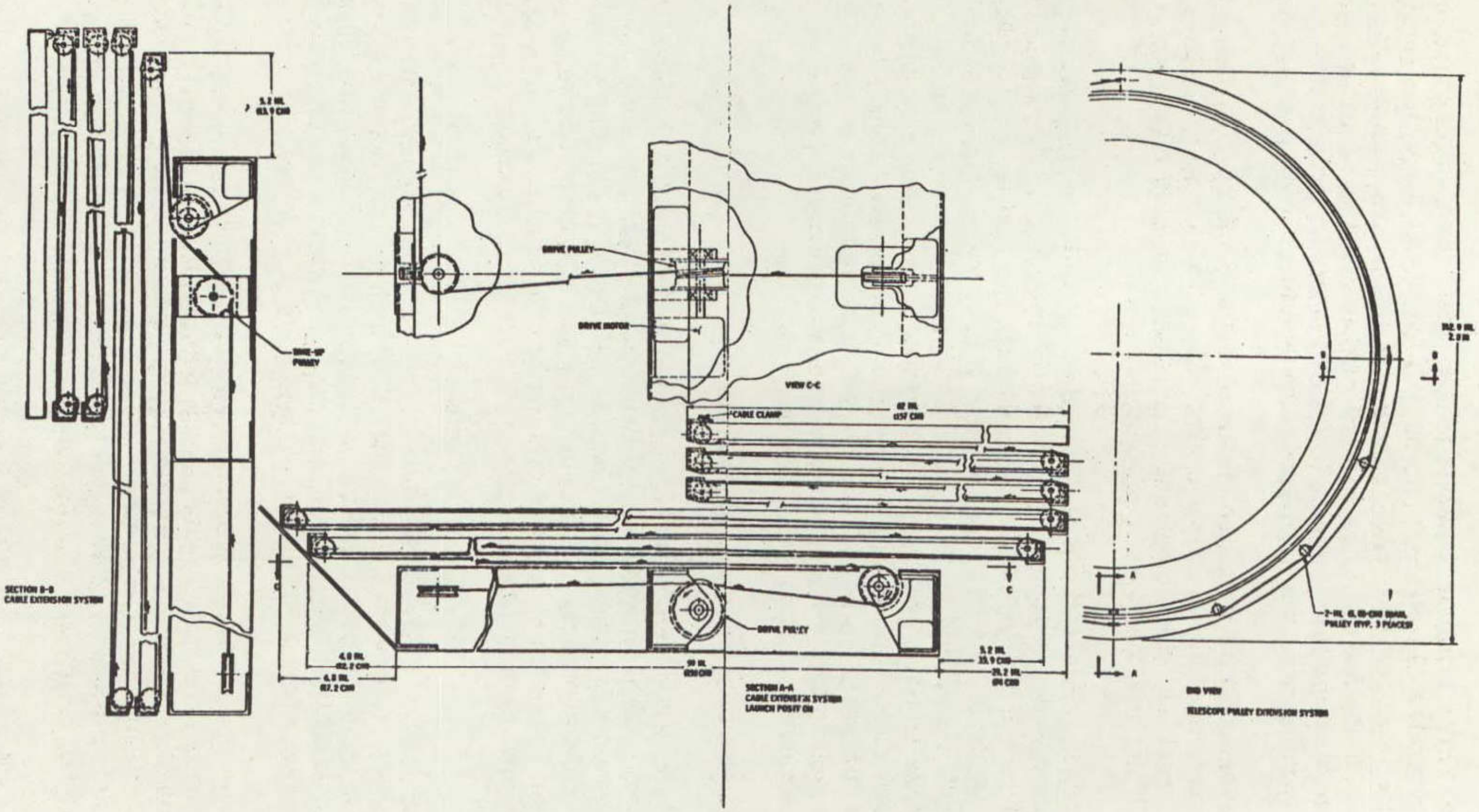


Fig. 22 Cable Extension System for LTEP Telescope

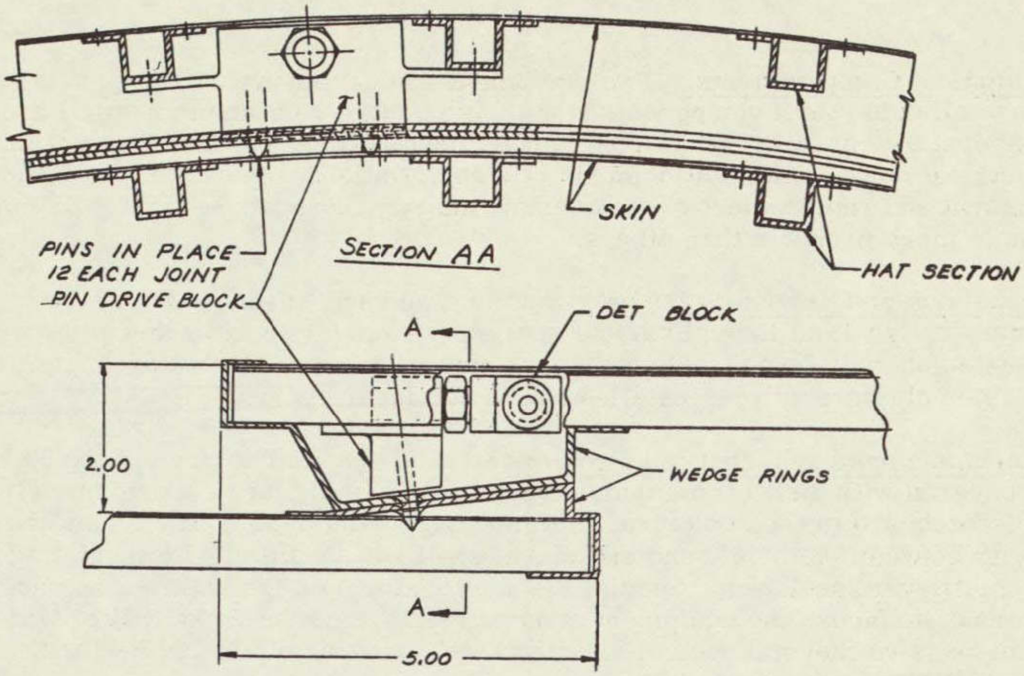


Fig. 23 Detail of Wedge Rings and Extend-Lock Pins

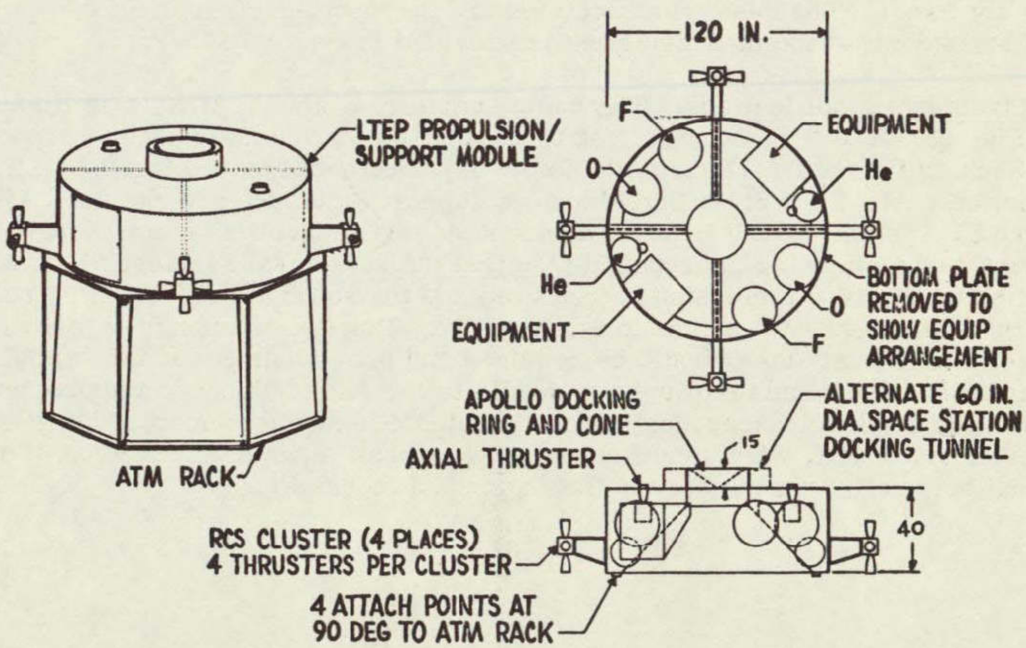


Fig. 24 Propulsion/Support Module for LTEP System

Equipment Compartments. Two equipment compartments will be provided to house all subsystem components requiring relatively uniform or small excursion temperature control. Flight control, communications and instrumentation, and electrical components will comprise the installations. Packaging will allow removal and replacement of modules, primarily those whose failure or malfunction is more probable than others.

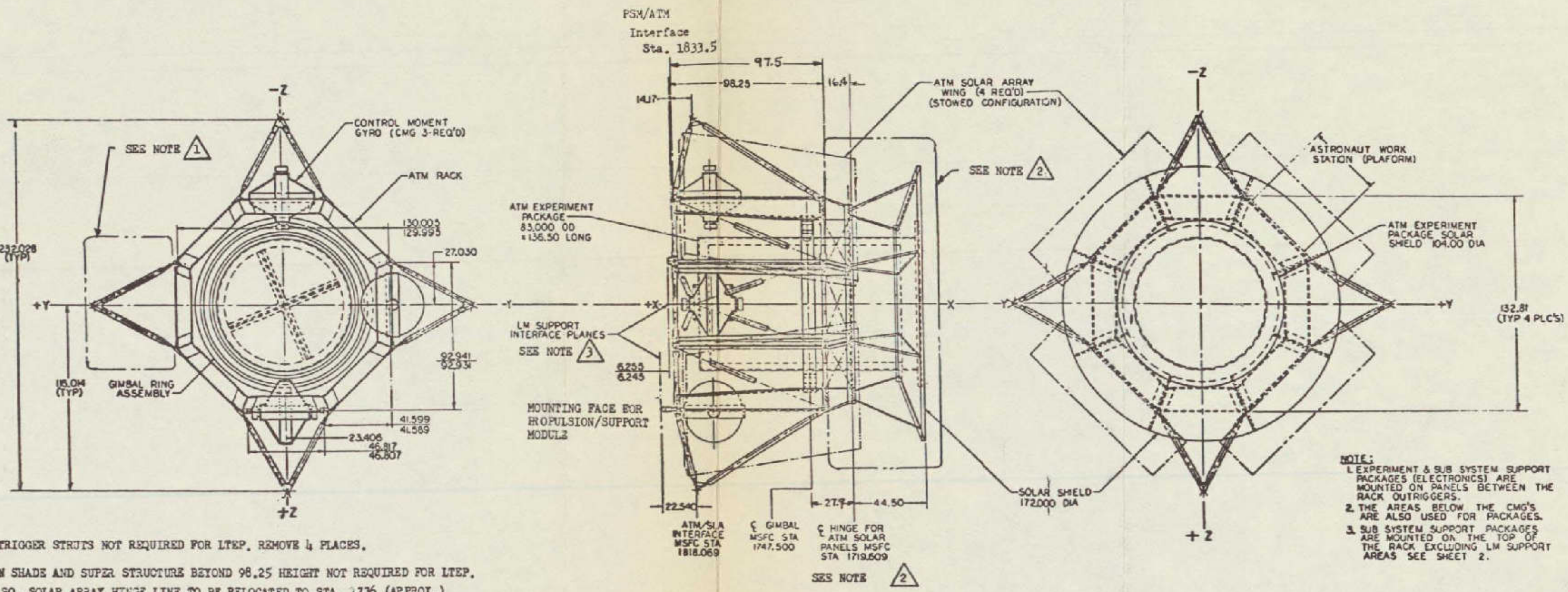
Propulsion and Thrusters. The propellant and pressurant tanks will be installed peripherally within the cylindrical shell as shown. Two axial thrusters will be mounted on radial webs and nozzles will extend through the bottom plate. Four thruster clusters will be installed on the outrigger beams.

Micrometeoroid and Thermal Protection. The external surface of the PSM will be covered with a sheet metal micrometeoroid shield placed approximately one inch out-board of the structural shell and supported by insulation standoffs. The cavity between the shield and structural shell will be fitted with insulating foam or multilayer insulation. Special thermal coatings on the external surfaces, the internal surfaces, the equipment compartments, and the tanks will provide a semi-passive thermal control arrangement, utilizing electrical heaters only to provide the necessary heat balances.

3.3.3 Modified ATM Rack

The ATM Rack, designed to support the Solar Telescope, is essentially adequate to use with the LTEP system; however, certain modifications are required to (1) remove structure and components not needed for the LTEP application thereby reducing the weight, and (2) adding single-axis rotation mechanisms for two ATM solar arrays (presently fixed). The basic modifications are discussed further in Section 3.4.3. The weight breakdown of the modified Rack is provided in Section 3.5.2.

Structural Modifications. The basic structure of the ATM Rack is illustrated in Fig. 25. The four outrigger strut assemblies, previously used to support the Rack on the Saturn Launch Adapter (SLA), are not required for the LTEP installation. Also, the Solar Shield and its support structure are not used with the LTEP system, which is not Sun-oriented. To reduce the overall length and weight of the structure, it is proposed also that the structural segment which is identified by the 16.4 dimension be removed and the solar array hinge line relocated approximately 12.4 inches to Station 1732. Finally, the mounting provisions for the LM Ascent stage should be removed and provisions added for 4-point attachment of the Propulsion/Support Module to the Rack bulkhead at approximately Station 1833.5. Except for protrusion of CMGs and equipment packages, the ATM Rack will, when modified, have an overall structural envelope of an octagonal prism; 133 inches across flats and 97.5 inches long.



LTEP NOTES:

1. OUTRIGGER STRUTS NOT REQUIRED FOR LTEP. REMOVE 4 PLACES.
2. SUN SHADE AND SUPER STRUCTURE BEYOND 98.25 HEIGHT NOT REQUIRED FOR LTEP. ALSO, SOLAR ARRAY HINGE LINE TO BE RELOCATED TO STA. 1736 (APPROX.)
3. PROVISIONS FOR LM ASCENT STAGE TO BE REMOVED. PROVIDE BOLT-CIRCLE BOLT-ON FOR 120 INCH DIAMETER PROPULSION/SUPPORT MODULE.

Fig. 25 ATM Rack and Modifications

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Equipment Changes. Figure 26 illustrates the equipment installations on the existing ATM Rack. Because of reduced electrical power requirements for the LTEP system, the following equipment will be deleted:

Item No.	Component	Quantity Removed	Weight Reduction
8	Measuring Distributor	1	26 lb
14	Charger/Battery/ Regulator Module (CBRM)	9	855
19	Switch Selector	2	40
37	Control Distributor	2	51
	TOTAL WEIGHT REDUCTIONS		972 lb

In addition, the net equipment mounted on the end bulkhead (Items 44, 45, 46, and 47) will be relocated outboard to clear the 120-inch diameter Propulsion/ Support Module or will be relocated to open areas on the vertical side panels (i.e., areas made available by equipment deletions). Items 15 and 16 also, must be relocated to another part of the Rack.

3.3.4 Modified ATM and Workshop Solar Array Installations

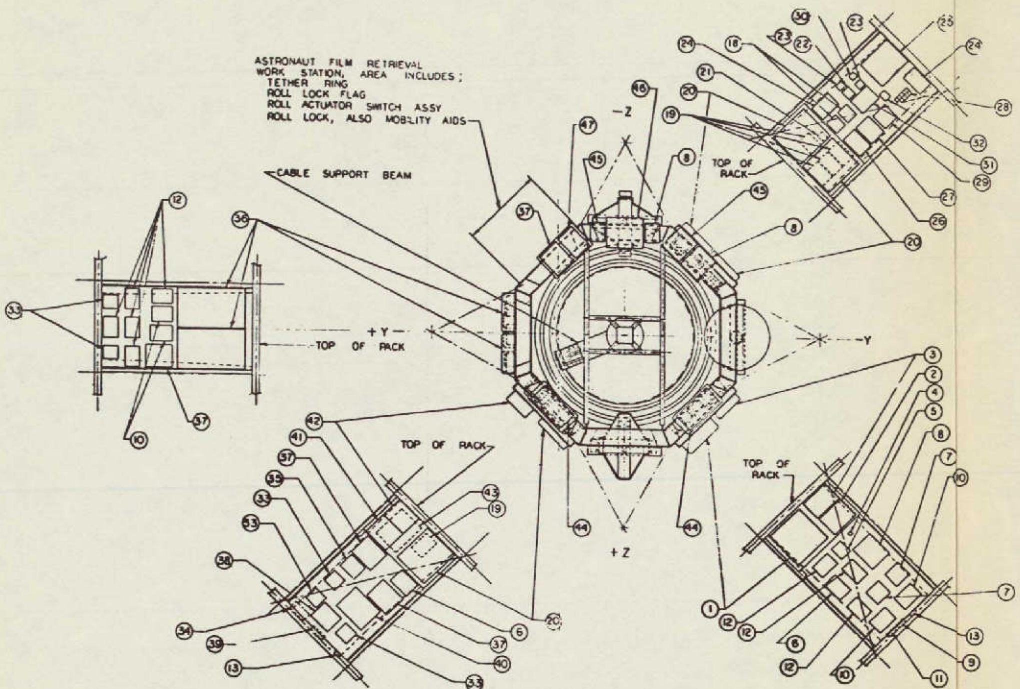
The current Dry Workshop Cluster configuration contains four ATM solar array wings fix-mounted to the ATM Rack and two Orbital Workshop (OWS) solar arrays fix-mounted to the SIVB structure. All arrays are folded for launch and extended after orbit-position is attained. Because of the complete spherical pointing requirement for the LTEP stellar-field pointing, single-axis rotatable solar arrays are required. Figure 27 illustrates the general configuration. The 360 deg rotation device for the ATM arrays will be a new-development item for LTEP. The ±180 deg rotation device for the OWS arrays is planned as a modification of the previous Saturn hardware. Section 3.4.3 describes the general requirement for, and characteristics of, the solar arrays.

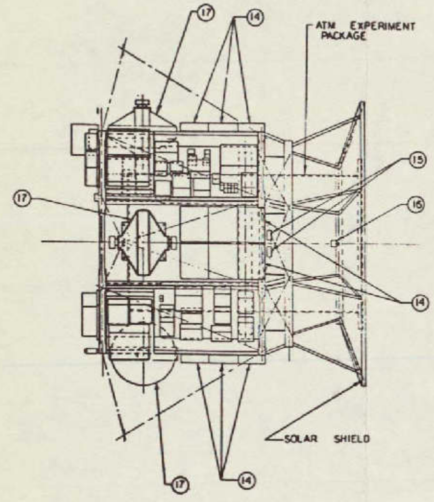
3.4 SPACECRAFT SUBSYSTEMS

The requirements for each LTEP supporting subsystem are explained and the conceptual design described in the following paragraphs.

3.4.1 Structural Subsystem Design

The structural configurations of the Propulsion/Support Module (PSM) and the ATM Rack were described in previous sections (3.3.2 and 3.3.3). This section is devoted to description of the basic telescope structure and the optical element supports; a discussion of the structural loads and their reactions; the weights of the telescope components; and the dynamic conditions in orbit affecting structural alignment and pointing.





NO.	COMPONENT
1	POWER TRANSFER DISTR
2	ATM DIGITAL COMPUTER
3	ATM DIGITAL COMPUTER INPUT/OUTPUT ASSY
4	J-BOX ASSY
5	COMMAND DECODER
6	MEASURING RACK (2)
7	REMOTE DIGITAL MULTIPLEXER (2)
8	MEASURING DISTR. NO. 1, 2 & 3
9	PCM / RF ASSY
10	MULTIPLEXER ASSY (4)
11	ASAP / RF ASSY
12	SIGNAL CONDITIONER RACK (8)
13	COAXIAL SWITCH (2)
14	CHARGER/BATTERY/REGULATOR MODULE (18)
15	ACQUISITON SUN SENSOR ELECTRONICS ASSY (2)
16	ACQUISITION SUN SENSOR (2)
17	CONTROL MOMENT GYRO (3)
18	TAPE RECORDER (2)
19	SWITCH SELECTOR (5)
20	CMG INVERTER ASSY (3)
21	NRL "A" POWER SUPPLY
22	SUBCOMMUTATOR ASSY
23	MEASURING VOLTAGE SUPPLY (2)
24	TELEMETER PCM/DDAS ASSY (2)
25	MAIN ELECTRONICS ASSY
26	CONVERTER DC TO DC
27	ASAP INTERFACE UNIT
28	J-BOX ASSY (9)
29	COMPUTER INTERFACE UNIT
30	NRL "B" POWER SUPPLY
31	MEMORY MODULE
32	COMMAND RECEIVER
33	REMOTE ANALOG SUBMULTIPLEXER (5)
34	VSWR MEASURING ASSY
35	FINE SUN SENSOR CONDITIONER ASSY
36	ATM CONTROL COMPUTER ASSY (2)
37	CONTROL DISTR NO 1, 2, 3 & 5
38	AMPLIFIER & SWITCH ASSY
39	DIRECTIONAL COUPLER
40	C & D LOGIC DISTRIBUTOR
41	AUXILIARY POWER DISTR
42	MAIN POWER DISTR
43	TRANSFR ASSY
44	BATTERY ASSY (2)
45	ATM RATE GYRO (2)
46	STAR TRACKER ASSY
47	STAR TRACKER ELECTRONIC ASSY

Fig. 26 ATM Rack Equipment Arrangement

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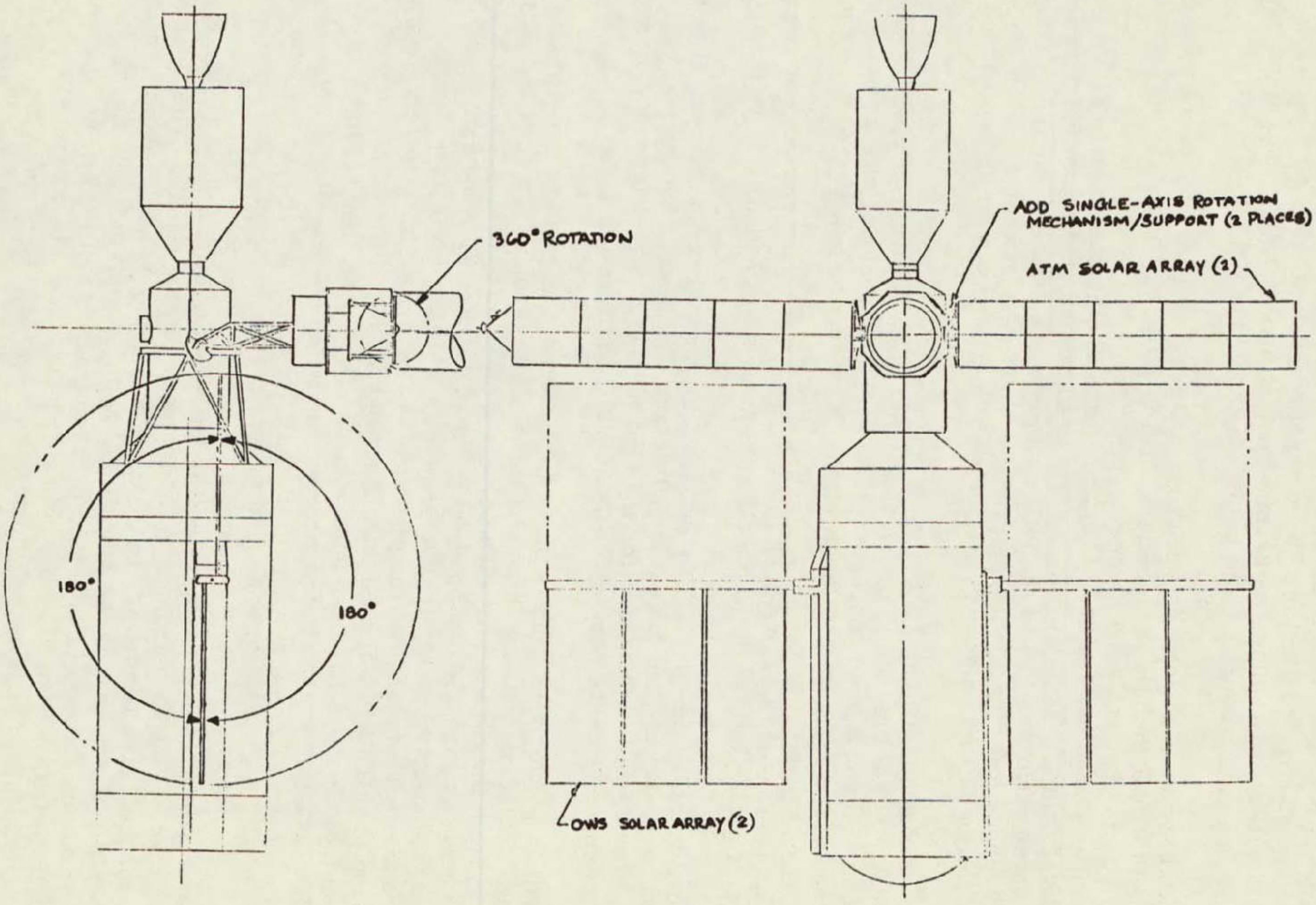

Fig. 27 Cluster/LTEP Solar Array Arrangement

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3.4.1.1 Basic Structure and Mechanism. The basic structure of the telescope is illustrated in Fig. 28. It is planned that the total structure will be aluminum alloy. To limit "permanent" deflections (under applied loads) to a minimum, all joining of segments will be by welding (resistance-spot or fusion) rather than by riveting or other mechanical fastening to eliminate "slippage" in joints.

The initial structural approach utilized an external skin on each of the telescope tube sections of 0.030-inch thick aluminum, stiffened by longitudinal stringers. The fixed section was further stiffened by intermediate rings. A typical cross-section of the tube shell is shown in Fig. 29. Also shown are the thermal control elements of external Optical Solar Reflector (OSR) covering and the internally-applied multilayer insulation. These stringers extend the full length of the cylindrical shell and are clip attached to the cylinder end rings and wedge rings. The wedge ring detail is shown in Fig. 23 (a description of the wedge ring and lock-pin function is given in Section 3.3.1).

Alternate concepts for the Tube structure, to replace the skin-stringer arrangement, are illustrated on Fig. 30. For equal weight, greater stiffness probably can be obtained using one of the alternate concepts. However, skin buckling effects must be throughly analyzed before an optimized (low weight – high rigidity) shell structure can be selected. The base of the telescope structure comprises a large 12 x 4 inch cross section girth ring which, attached to a one-inch thick primary mirror support plate, establishes an extremely rigid platform to which all structural alignment will be referenced.

The equipment bay is a typical cylindrical sheet metal compartment, segmented into a central compartment and six equal radial compartments. Access doors to each of the compartments will be provided for in-orbit inspection, maintenance, data retrieval, and experiment replacement/replenishment by astronauts.

The ballast platform is a heavy plate (probably a steel shallow pan structure filled with lead and sealed) which is mounted on three sliding tube assemblies and actuated toward or away from the gimbal-ring plane by two motorized screw jacks located between adjacent access doors 180 deg opposed. The platform will be retracted for the launch-stowed configuration to statically balance the retracted telescope mass. During telescope erection on orbit, the platform will be driven to the extended-stop position. The stop position will adjusted during ground testing after the actual weight and balance data on the telescope has been determined. The actual longitudinal center-of-gravity position, relative to the gimbal ring pivots, is quite critical relative to the ATM rack pointing control system responses (the c.g. of the gimballed mass on the Solar Telescope is required to be within ±0.50 inch of the gimbal plane).

One or more large access doors will be provided in the fixed section of the telescope tube for access by an astronaut to the primary mirror cavity. The astronaut will perform inspection, cleaning or, in the extreme, removal and replacement of mirror segments. The door must be a sealing type to prevent entry of contaminants to the mirror during ground, launch, and orbit operations. It also must be capable of being readily opened and closed by a single astronaut. Special care must be taken in later design detailing to assure that the door does not bind because of structural loads on the telescope and that the adjacent structure does not "sag" when the door is opened and prevent subsequent closing.

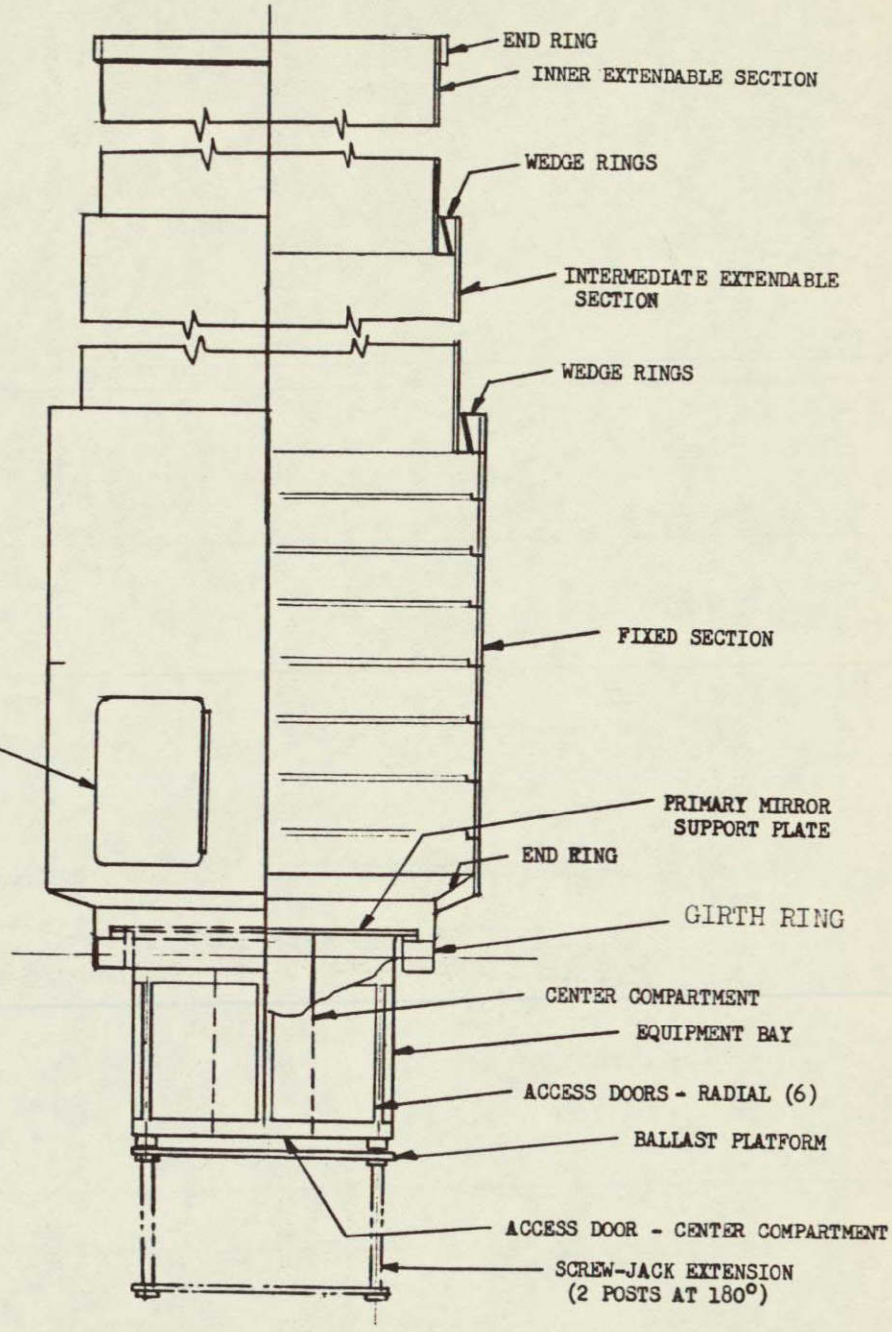


Fig. 28 Telescope Basic Structure

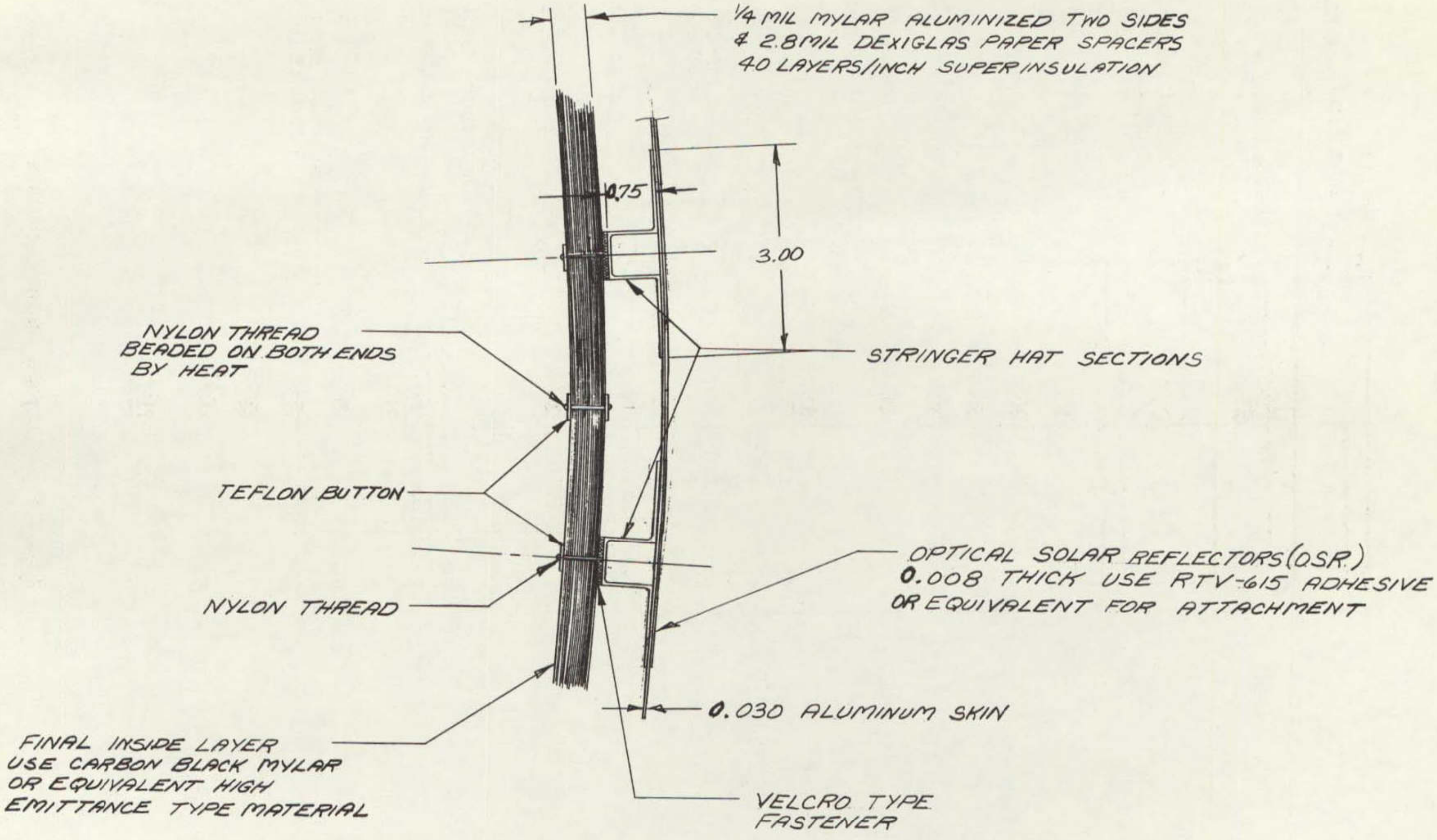
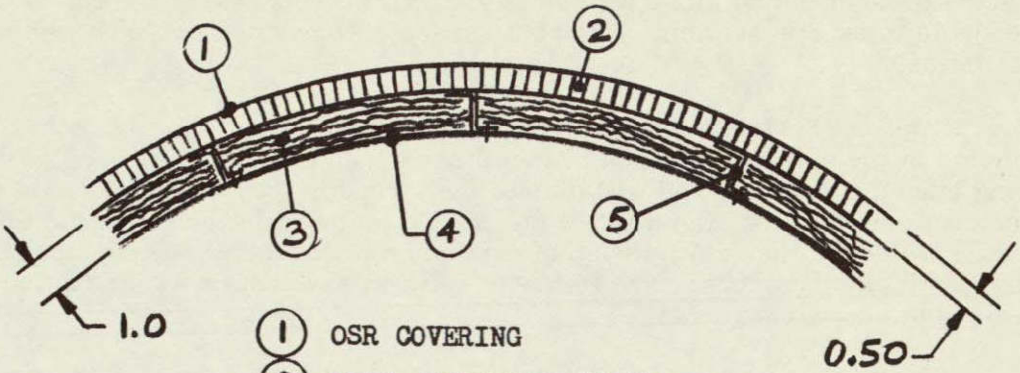
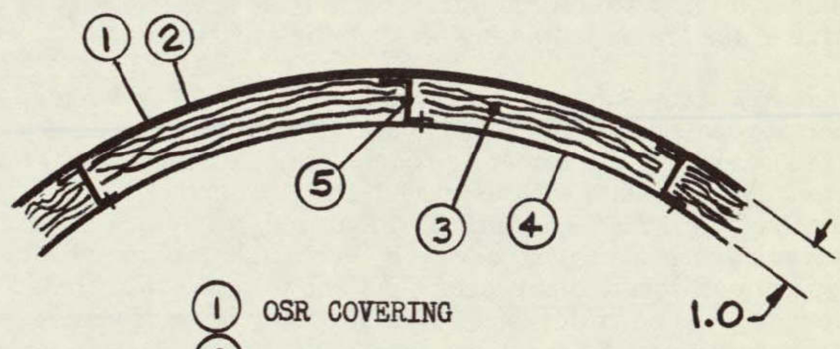


Fig. 29 Typical Cross-section of Telescope Tube Design



(1) OSR COVERING
(2) ALUM. HONEYCOMB SANDWICH
(3) MULTILAYER INSULATION
(4) ALUM. INNER SHEET-ANODIZED BLACK
(5) INSULATION STANDOFFS

(a) HONEYCOMB SANDWICH OUTER SHELL



(1) OSR COVERING
(2) ALUM. OUTER SHELL (NO STRINGERS)
(3) MULTILAYER INSULATION
(4) ALUM. INNER SHEET — ANODIZED BLACK
(5) INSULATION STANDOFFS

(b) MONOCOQUE OUTER SHELL

Fig. 30 Alternate Structural Concepts for Telescope Tube

An actuator to open and close the sun shield will be required at the end of the inner extendable telescope section. Figure 31 shows a conceptual design of the actuator installation.

3.4.1.2 Optical System Support. The support and mechanical alignment of the optical elements is the primary function of the telescope structure. The major loads will occur during launch and ascent and will dictate the strength of these structures. Physical placement and relative alignment of the optical elements after telescope erection will strongly influence the detail design of extension mechanisms, mechanical stops, spacer rods, and locking devices. The following paragraphs contain a description of the optical element support features.

Primary Mirror Support. The primary mirror segments and their positioning mechanisms will be mounted on the aforementioned one-inch base plate.

Secondary Mirror Support, 6-Section Telescope. The launch-stowed arrangement for the earlier 6-section telescope is shown in Fig. 32. The four quartz rods (mounted in housing) which support the secondary mirror frame must be hinged and folded as shown to allow retraction of the telescope tube sections with this telescope design. The lower quartz rod sections mount rigidly against the base plate. Upon erection, the rods will be unfolded after the sun shade is opened and as the secondary mirror frame is raised by the tube section to which it is attached. Guide roller supports on the tube section will maintain alignment of the quartz rods with the bottoming pins on the mirror frame. Upon attainment of extended position, the bottoming pins will rest on the end surfaces of the quartz rods, thereby providing a fixed length between the base plate reference and the secondary mirror frame (the mirror has been precision-adjusted in position relative to the frame bottoming pins during initial assembly).

Secondary Mirror Support, 3-Section Telescope. The longer length of the 3-section stowed-condition telescope allows use of a one-piece quartz rod to support the secondary mirror at a predetermined distance from the secondary mirror. All elements will be ground-installed and optically checked out prior to launch of the LTEP system. The four rods, one inch in diameter, will be protected during launch and ascent by enclosure in a metal tube housing which will sustain all longitudinal loads. As shown in Fig. 32, the secondary mirror frame webs will be roller-supported at each tube-wall contact point to allow free vertical movement of the mirror frame relative to the telescope structure. Tension springs will maintain contact between the mirror frame and the spacer rods; these springs will be pre-loaded to assure there is no separation of the contact surfaces during negative g loads in launch and ascent. A small gap between the rod metal housing and the mirror frame load point will close as the quartz rod deflects under launch loads and the major loads then will be borne by the metal housing.

The simplicity of the one-piece quartz rod installation and the desirability of a pre-launch adjustment of the on-orbit mirror spacing makes the 3-section telescope concept extremely attractive.

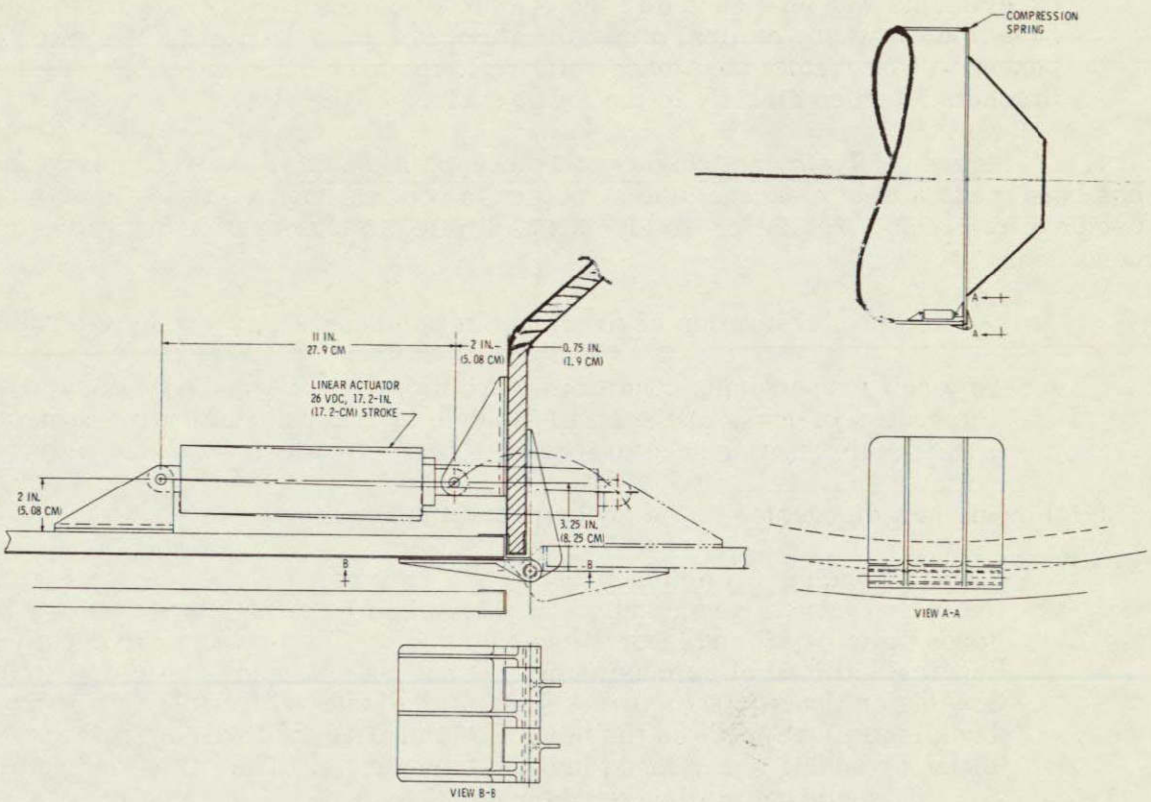


Fig. 31 Sun Shield Actuator Installation

Figure Sensor Support. The Figure Sensor mounting frame, comprising a central housing and four radial webs, will be roller-mounted to the inner wall of the telescope tube section. These rollers will be mounted on longitudinal tracks, allowing longitudinal movement of the frame/sensor assembly to accommodate both the stowed and the extended positions of the Figure Sensor relative to the inner telescope tube section. Springs will be provided to "pull" the sensor/frame to its erected position against mechanical stops on the roller tracks. Figure 33 shows the concept.

Optical Experiments Support. The other optical system components and specific experiments will be mounted in the equipment compartments below the one-inch base plate. Where critical dimensional correlation is required. the affected component will be rigidly positioned relative to the base plate, possibly with mounting brackets attached directly to the lower surface of the plate.

3.4.1.3 Stress Analysis and Weights of Telescope Elements. A preliminary analysis has been made of the telescope tube structure to confirm that weight estimates being used are reasonably realistic. Analysis was limited to examination of two basic loading conditions:

a. An ascent acceleration environment of combined 6g aft and 2g lateral only.

b. An orbit maneuvering condition where the telescope would be rotated about the center-of-mass of the LTEP Module by the attitude control thrusters; a maximum angular acceleration of 1 deg/sec^2 was assumed.

The following is a discussion of the analysis and the results.

a. Ascent Loading – Combined 6g Aft and 2g Lateral. The telescope, in its retracted launch configuration, must sustain relatively large longitudinal loads up to 6g aft and lateral loads up to 2g. The forward, or negative, longitudinal load of 2g maximum does not establish any critical structural loading on the tube structures. The aft 6g loads will establish a compression buckling failure mode in the tube; the lateral 2g load will aggravate the condition by adding shear loads into the tube panels. The basic loading diagram for this condition is illustrated on Fig. 34.

   The analysis assumed that the aft end of each tube section is restrained against aft-acting and lateral loads. The forward ends of the inner and intermediate tubes are restrained by the fixed section against lateral loads and forward-acting loads. The analysis revealed that a stringer-stiffened shell structure described previously would adequately sustain the loads. Additionally, a ring-stiffened shell (ring spacing at 30 inches) would also provide an adequate structure well within the weight margins used. A preliminary analysis was also completed on a comparative, alternate honeycomb sandwich structure. It is estimated that use of the structural sandwich could reduce the telescope tube weight, excluding end rings, approximately 40 percent.

   The maximum bending moments acting upon the tubes are 63300, 63350, and 51500 inch lb respectively for the inner, intermediate, and fixed sections.

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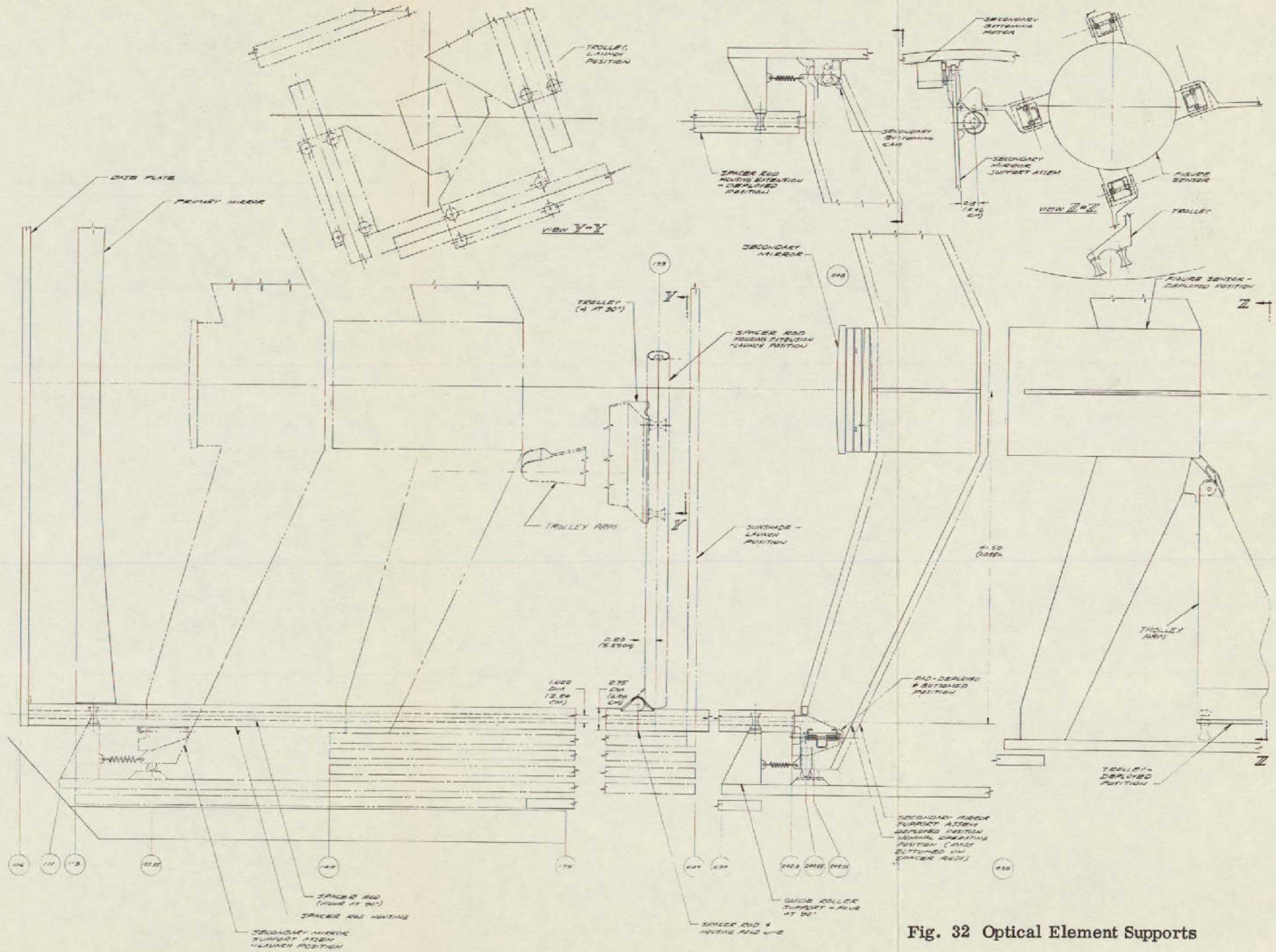

Fig. 32 Optical Element Supports

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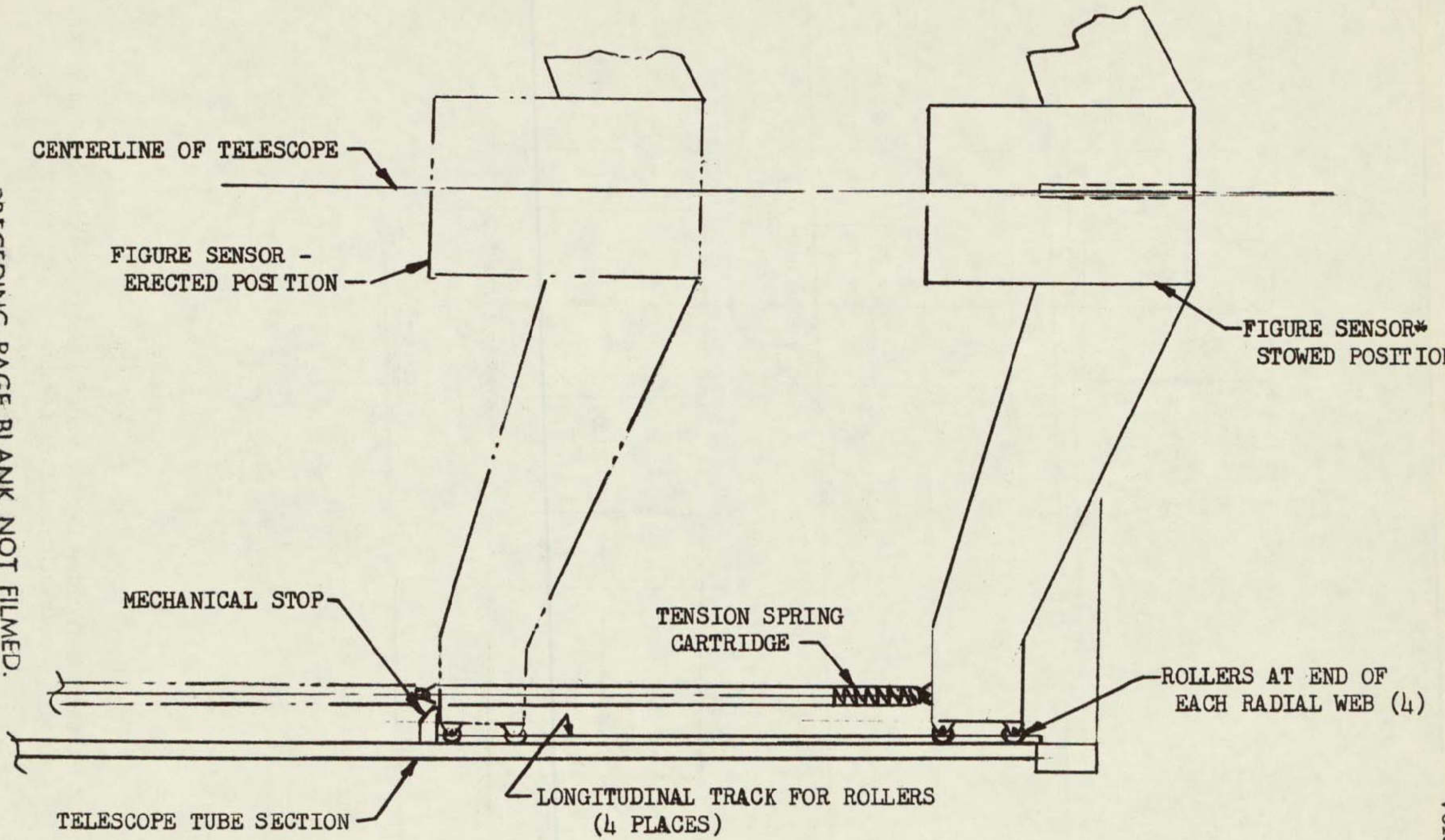

Fig. 33 Concept for Figure Sensor Movement From Stowed to Erected Position

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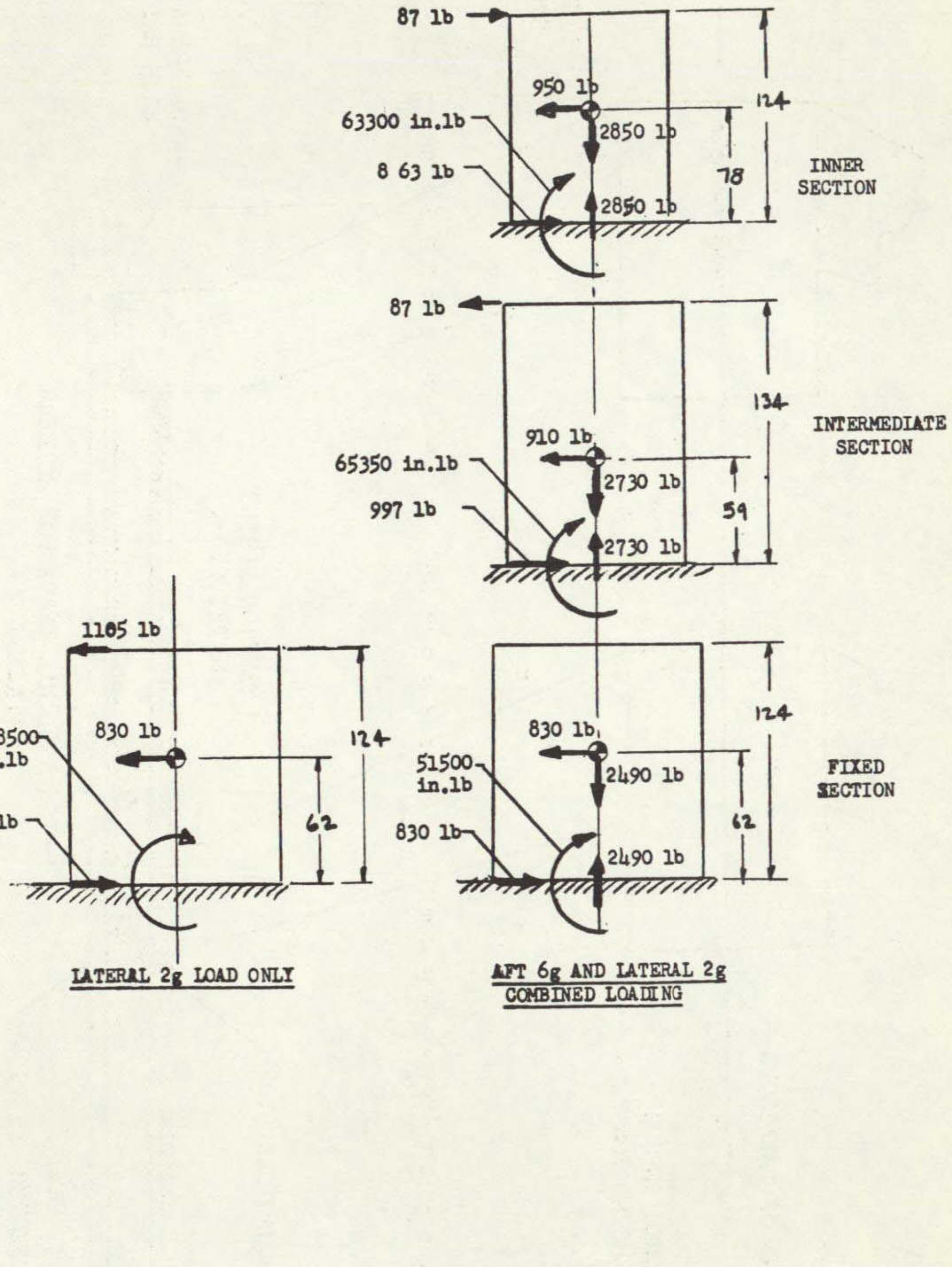


Fig. 34 Structural Loading Conditions of Telescope Tube in Launch and Ascent Accelerations (Limit Loads)

b. Ascent Loading – 2g Lateral Only. Because there may be ascent conditions, perhaps during stage separation, where fore-aft loads may be essentially zero, a loading condition of 2g lateral only was analyzed. Without the aft-directed "hold-down" load, the bending moment in the fixed section of the tube increased to 188,500 inch lb. This was used as the critical load for detailed analysis of the structural shell.

c. Loading Due to Angular Acceleration of 1 deg/sec^2. The structural loads in the tube resulting from angular acceleration established a maximum bending moment in tube sections of about 3000-inch lb (compared to 50,000-inch lb for launch-ascent). A bending moment diagram is shown in Fig. 35. Except for consideration of minor structural deflections, the angular acceleration loading is not a governing structural criteria.

d. Weights of Telescope Elements. The weights and locations of masses assumed for the structural analysis of the telescope are listed in Table 2.

3.4.1.4 Structural Dynamics. Preliminary analyses were performed to determine the approximate movement of the telescope tube structure resulting from orbit maneuvering and temperature changes during a typical orbit. The results are described following:

a. Maneuvering Deflections. At the aforementioned angular acceleration of 1 deg/sec^2, the structural tube will deflect a very small amount. The center of the Figure Sensor will shift only 0.0005 inch from the theoretical vertical centerline through the center of the primary mirror. The acceleration assumed was typical of that induced by the attitude control thrusters although these thrusters will probably not be activated during the continuous fine-pointing mode. The angular accelerations imparted by the CMG and Fine-Pointing Control Systems in the ATM Rack are estimated to be less than the 1 deg/sec^2. In follow-on analyses during Phase B, the specific rates will be verified.

b. Potential Structural Distortions Due to Temperature. A brief study of distortions resulting from uneven heating of the telescope tube in orbit was accomplished. Figure 36 illustrates the location of the maximum and minimum temperatures on the tube and the temperature difference. A simple linear temperature-gradient change around the circumference was assumed. Because of the inertial steller-pointing mode of the LTEP system, the temperature at any point along any longitudinal element of the telescope tube was assumed a constant at any point in time. The orbit orientation is shown in Fig. 37. Using the worst-case condition of an 80°F temperature difference between two longitudinal elements 180 deg opposed, a thermal deflection was calculated. Figure 38 illustrates the telescope tube in cross-section and identifies the types of deflection. It was determined that the secondary mirror optical center was displaced from the vertical centerline through the primary mirror center by 0.23 inch. No tilting of the secondary mirror occurred because the equal-length quartz rods were deflected in bending but maintained (by parallellogram action) the secondary mirror plane parallel to the primary mirror base. The Figure Sensor, resting on the stop block (described in Section 3.4.1.2) will be translated laterally but will also be tilted out of a plane horizontal and parallel to the primary mirror base. The angle of tilt will be 800 arc sec; the displacement from the theoretical line-of-sight will be 1.0 inch.

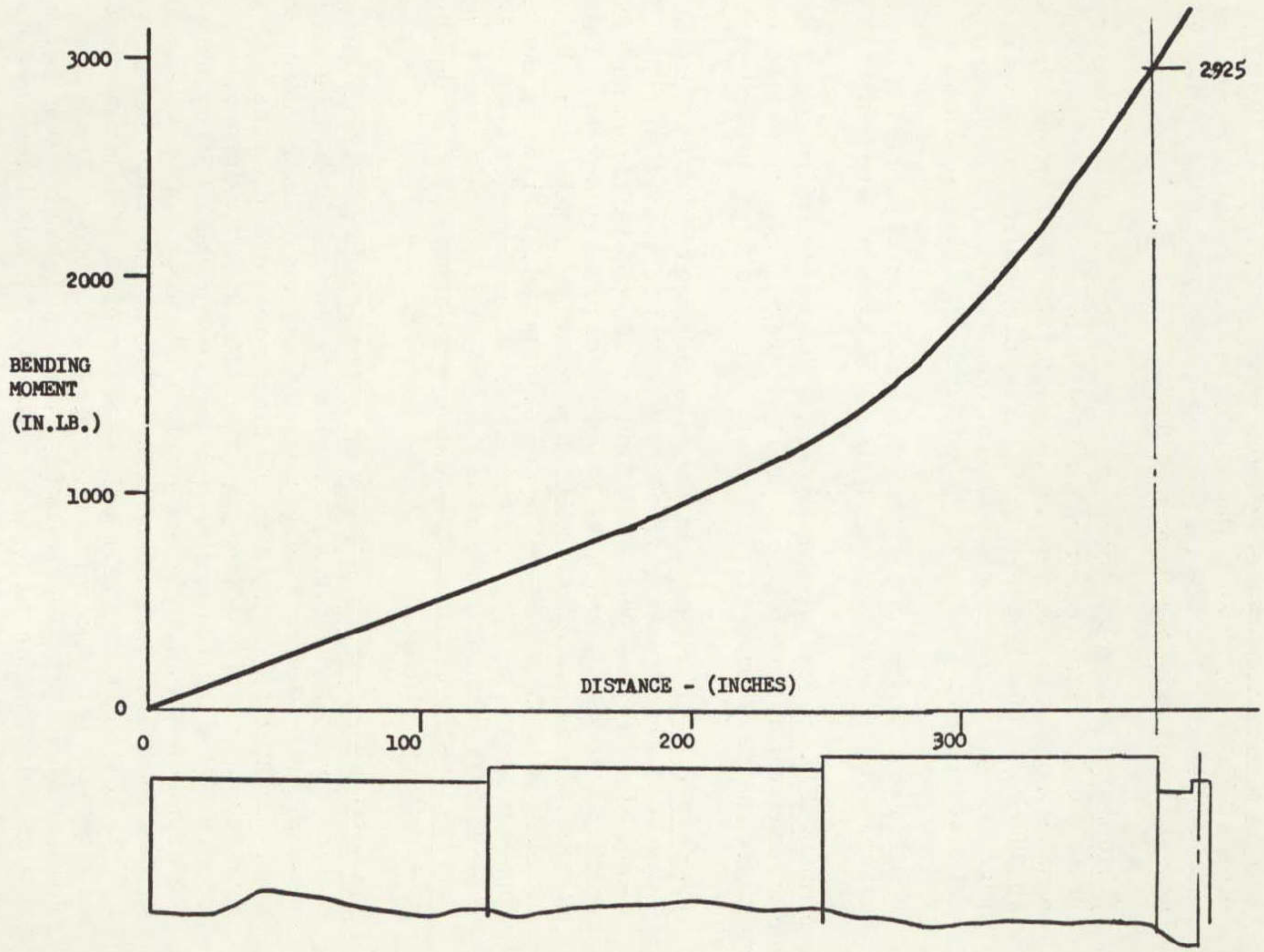


Fig. 35 Bending Moment Diagram for Angular Acceleration of 1 deg/sec^2

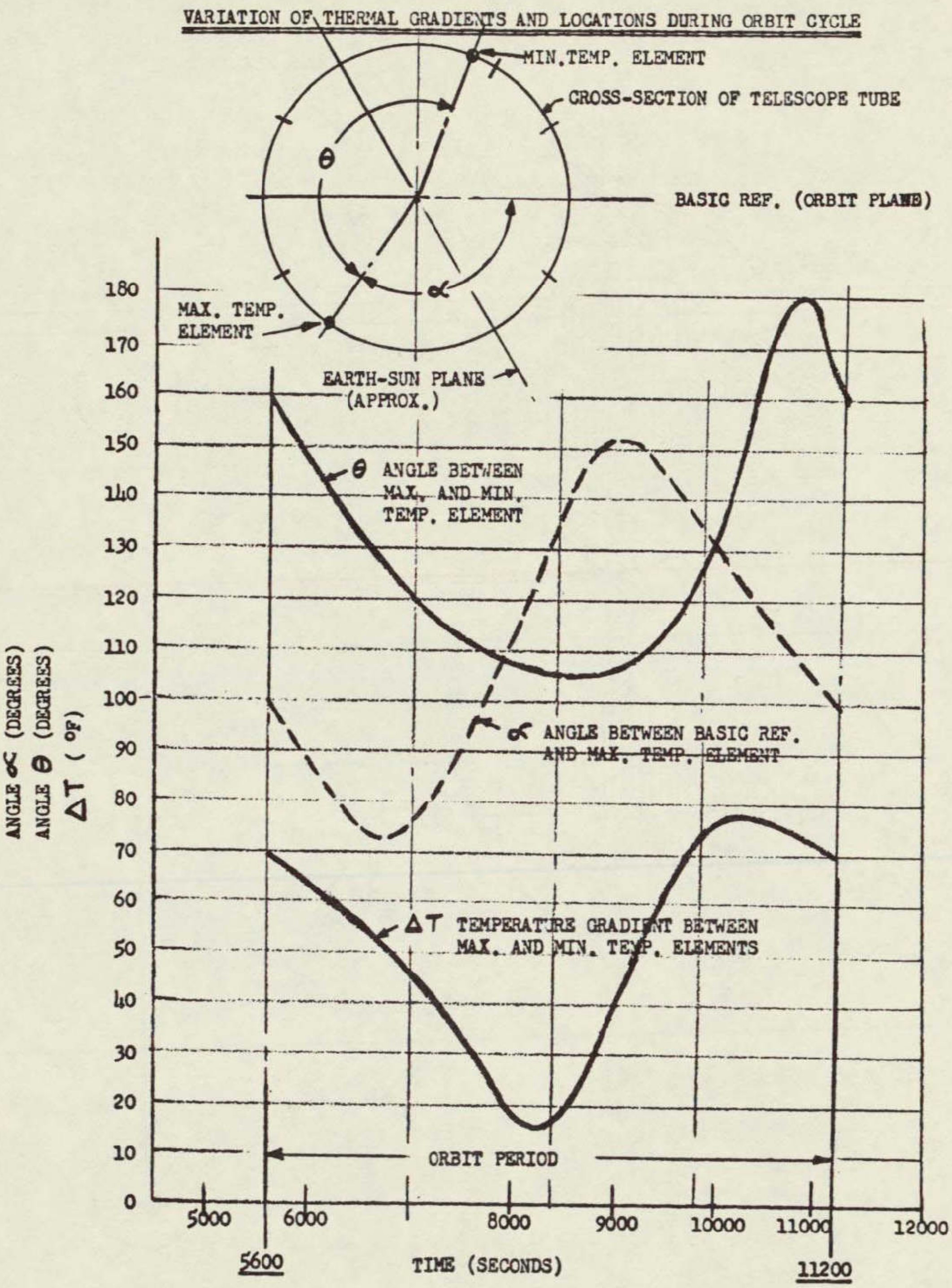


Fig. 36 Variation of Thermal Gradients and Locations During Orbit Cycle

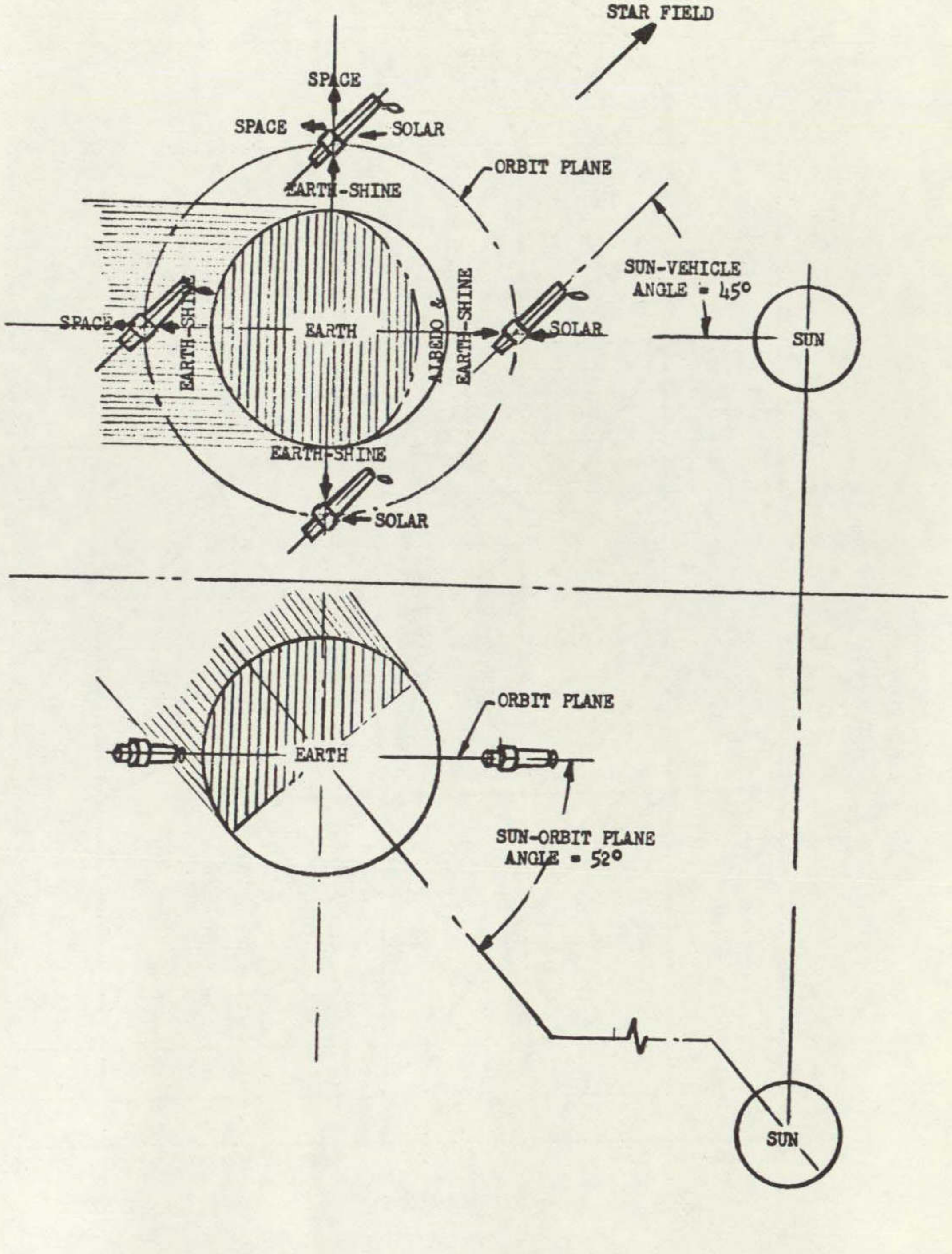


Fig. 37 Orbit Orientation of LTEP Vehicle

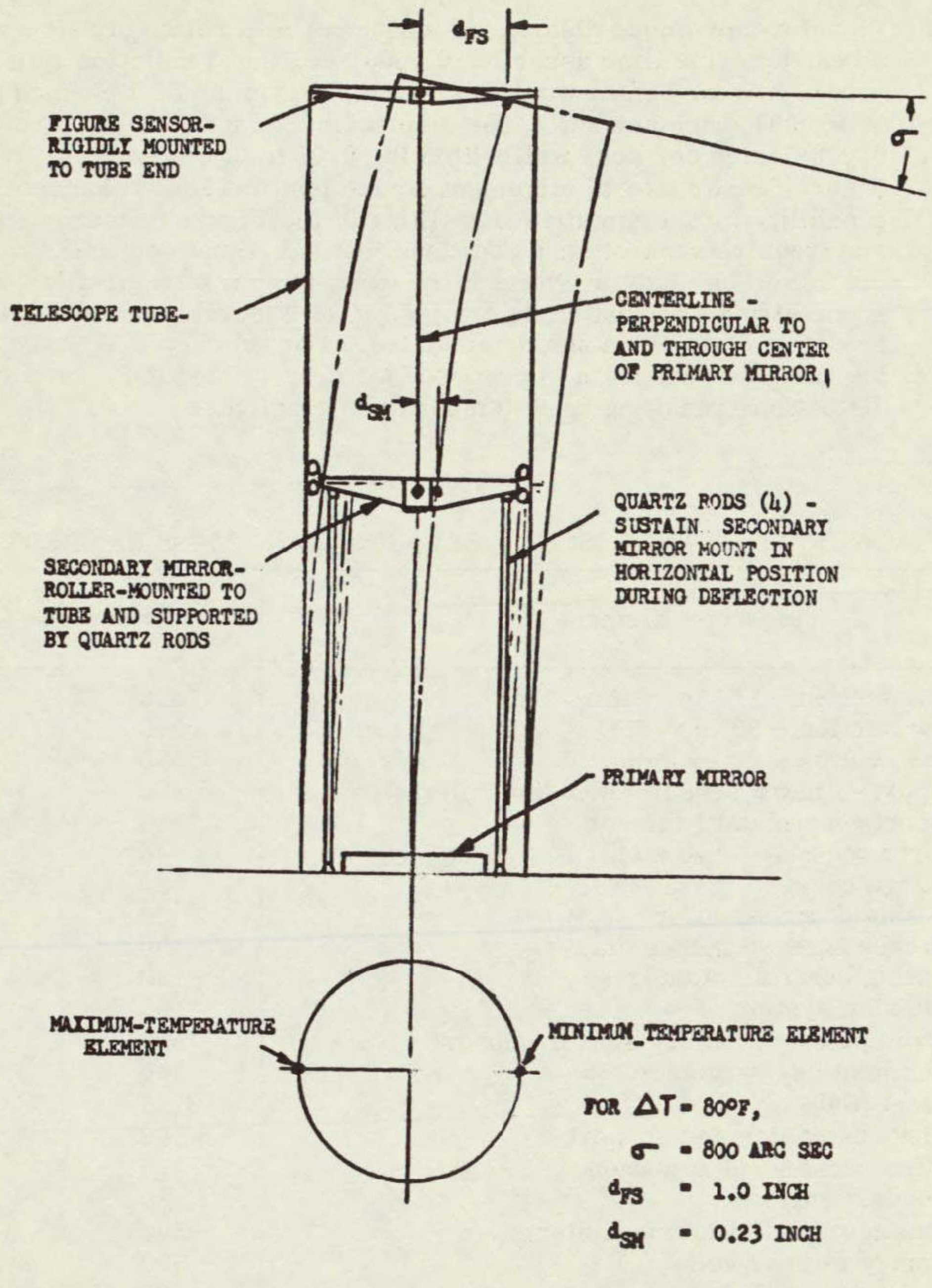


Fig. 38 Deflection of Telescope Tube with Thermal Gradients

The aforementioned distortions will occur at a relatively slow rate. With a heat-up cycle time assumed of 1500 sec, the translation rate of the secondary mirror center would approach a maximum of 0.23 inch per 1500 sec or 0.00015 inch per sec. The displacement rate of the Figure Sensor is 0.00067 inch per sec, well within the 0.01 to 0.1 sec for full travel of the Figure Sensor lateral alignment device (estimate for alignment device rate capability). The simultaneous tilting of the Figure Sensor support frame may require separate and additional optical adjustment techniques. During the follow-on study in Phase B the exact temperature profiles on the telescope structure must be determined in considerably more detail and the resulting distortions again calculated. For this detailed analysis, an existing computer program is proposed for determining the structural loads and distortions resulting from temperature gradients.

Table 2

WEIGHTS OF TELESCOPE ELEMENTS AND MASS CENTERS

Telescope Element	Weight (lb)	Location* (inches)
Tube section – 114 inch dia.	415	78
Tube section – 99 inch dia.	375	197
Tube section – 89 inch dia.	330	321
Support – figure sensor (including rollers)	20	330
Support – secondary mirror	10	155
Quartz rods (4) – 140 inch	40	75
Stowage cover	20	375
Sun shield and actuator	30	388
Gimbal ring – 80 inches dia.	190	0
Pointing control actuator	132	0
Extension system	100	250
Bottom plate – primary sensor support	503	7
Equipment bay structure	200	(-25)
Ballast plate	3185	(-85)
Ballast extension and support	100	(-75)
Figure sensor and actuation	75	343
Secondary mirror	50	152
Primary mirror and mechanisms	800	10
Primary mirror cell	500	10
Film and experiment supplies	200	(-35)
Electro-optical system	821	(-35)
Summation	8096	0

*NOTE: Locations given are measured above and below the centerline of the gimbal ring. All negative dimensions are below the gimbal plane. All measurements are to mass center of element listed.

c. Dynamic Response Characteristics. The ratio of the telescope tube diameter to the length is rather large and therefore the structure is stiff in bending. This appears verified by the very small, 0.0005 inch, deflection under conservative and exaggerated maneuvering accelerations. It is presumed therefore that the telescope will react essentially as a rigid body when considering the overall dynamic response of the telescope/gimbal/ ATM Rack System.

The inertial characteristics of the LTEP Telescope Assembly are quite different from those of the ATM Spar and Solar Telescope. The gimballed masses have inertias of respectively 23,280 slug-ft^2 and 2485 slug-ft^2, approximately an order of magnitude difference. The effect of this inertia change on the coupled-response with the Pointing Control System in the ATM Rack (which provides gimbal ring torquing) has not been analyzed in detail. It is possible that the larger moments of inertia on the LTEP will further dampen external vibrations or movements and result in improved stability of the telescope. However, the response characteristics of the gimbal control system must be analyzed in detail during the Phase B follow on effort and the capability of existing hardware (such as gimbal torque motors) verified.

3.4.2 Orbital Propulsion Subsystem

The LTEP Module, in the free-flight mode, will be required to provide orbit maintenance periodically, and coarse-pointing to the stellar target at the beginning of any star acquisition phase. Conversely, when the LTEP Module is attached to the AAP Cluster, the Cluster Thruster Attitude Control System (TACS) will provide all maneuvering and coarse-pointing for the LTEP system and the propulsion/attitude control subsystem of the LTEP Module will be dormant. It has been determined that a liquid bipropellant system, utilizing proven components from the Apollo CSM and LM vehicles, is adequate for the LTEP Propulsion subsystem and will provide compatibility among the Cluster, CSM, and LTEP Module propellants for propellant resupply operations. The propellant quantity requirements and the function of the subsystem is discussed in the following paragraphs.

3.4.2.1 Station Keeping and Coarse Pointing Maneuver Requirements. The requirement to stay above a 210 nm altitude for the LTEP mission duration will require a thrust impulse of 35 ft/sec each 127 days (for the LTEP free-flight mode). This is based upon a near minimum solar activity, as is predicted for 1974-1975, with conservatism to cover the predicted uncertainties for that time period. (Orbit drag decay and maintenance requirements are in Appendix B – Orbit Mechanics Parameters.) For the LTEP system to operate for two years between resupply operations over a total period of 10 years, the propulsion tankage should be sized for a time-span including a period of maximum solar activity, also including conservatism to cover uncertainties. Based on these premises, the spacecraft will require 35 ft/sec maneuvers on the average of once every 36 days over the two-year period, or a total delta velocity capability of 730 ft/sec. With a typical specific impulse of 290 sec for 100 lb-thrust and 500 lb-thrust thrusters proposed, the tankage should accommodate approximately 2100 lb of useable propellant. A resupply interval of less than two years would reduce this requirement.

In addition to orbit maintenance propellant, additional small amounts will be required to perform the following orientation or position-holding maneuvers:

- Position-hold during CMG spin-up
- Backup for CMG desaturation
- Station-keeping with Cluster
- Compensation for torques caused by solar pressure and aerodynamic loads
- Star-field acquisition (coarse-pointing) at beginning of each viewing period.

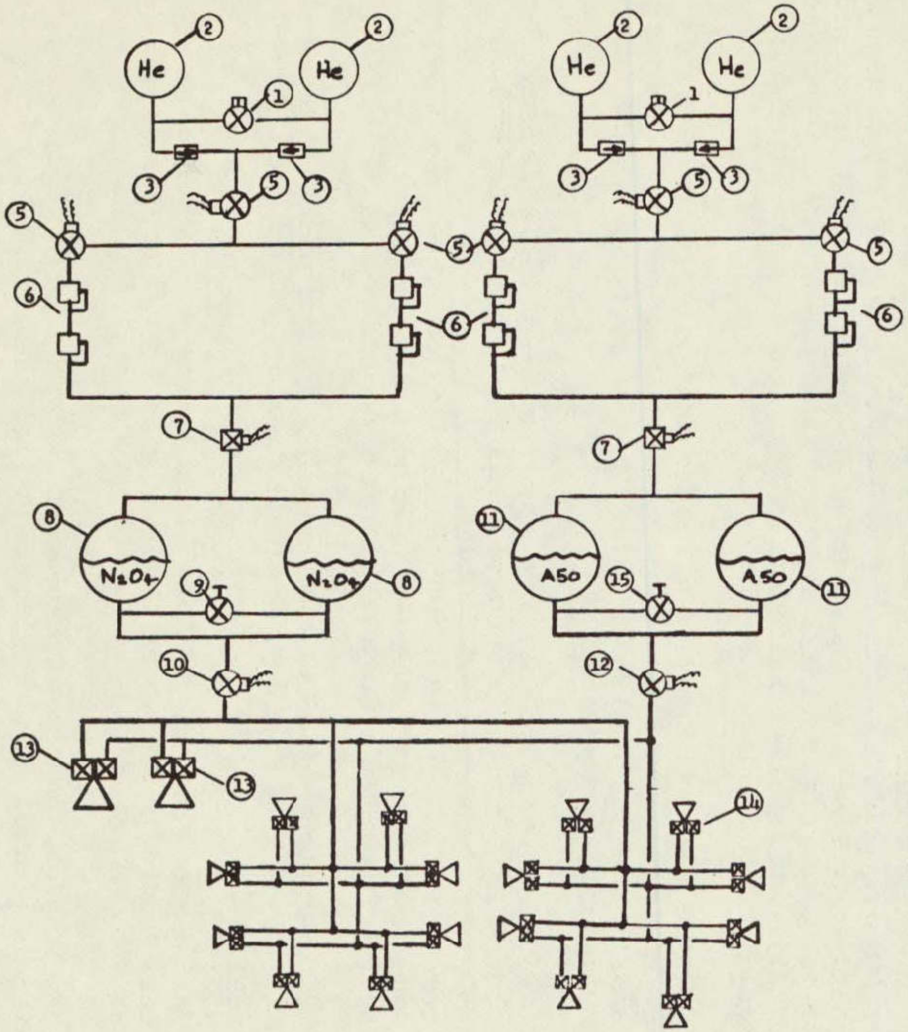
The amount of propellant used for these maneuvers is small compared to that required for orbit maintenance except that for CMG desaturation which may require as much as 6 lb per orbit. However, this is an emergency backup mode for the planned gravity-gradient desaturation which is scheduled for accomplishment by the CMGs.

Approximately 500 lb of propellant has been allocated for maneuvering and 2100 lb for orbit maintenance. The propellant tanks have been sized for the total 2600 lb useable. For the baseline configuration of the LTEP Propulsion and Support Module, a nominal 2200 lb total useable propellant has been assumed carried in the oversize tankage, on the basis of probable statistical reduction of the aforementioned conservative worstcase requirements for 2600 lb.

3.4.2.2 Propulsion Subsystem Components, Function, and Weight. To provide for delta velocity changes, two axial thrusters, each 500 lb thrust level have been selected. For attitude control, four sets of thrusters (four thrusters per set) have been provided and are installed on outrigger struts on the Propulsion/Support Module (See Fig. 23 for the general module configuration).

A schematic of the proposed subsystem is shown on Fig. 39 (a). Bladder-type propellant tanks are used so that zero-g operations can be performed with positive fluid pressure available to the thrusters at all times. Both the axial thrusters and attitude control thrusters are supplied from the single propellant control and feed system. Redundancy and control cross-coupling in the thruster installations allows continued operation with 50 percent of the thrusters failed.

A preliminary list of components is given in Fig. 39 (b). All of these components have been space-qualified on previous Apollo CSM or LM programs except the propellant tanks, which are specially sized for the LTEP Module. However, the elements of the tanks (standpipe, bladder, etc.) have been qualified. Most of the componetry has been tested to affirm high reliability levels but some additional life-cycling tests may be necessary to verify capability for the two-year LTEP operational life span. It is expected that few, if any, of these components will survive an on-off usage cycle for the longer 10-year operating period. Also, replacement of the total Propulsion Subsystem incrementally in orbit does not appear feasible. It, therefore, may be appropriate to consider the replacement of the complete Propulsion/Support Module at intervals. The replacement operation is totally feasible utilizing the following basic approach:



ITEM NO.	COMPONENT	QTY.	WEIGHT (LB)
1	FILLVALVE - HELIUM	2	
2	TANK - HELIUM (3500 PSI)	4	140
3	CHECK VALVE - HELIUM	4	
4	VALVE - PYROTECHNIC OPEN	2	
5	VALVE - LATCHING SOLENOID - HELIUM	4	
6	PRESSURE REGULATOR - HELIUM	4 PAIR	
7	SHUTOFF VALVE - MOTOR DRIVEN - HELIUM	2	
8	TANK - OXIDIZER - CAPY. 750 LB. 26 DIA x 36 INCHES - BLADDER TYPE	2	60
9	FILL VALVE - OXIDIZER	1	
10	ISOLATION VALVE - OXIDIZER	1	
11	TANK - FUEL - CAPY. 750 LB. 26 DIA. x 36 INSHES - BLADDER TYPE	2	60
12	ISOLATION VALVE - FUEL	1	
13	THRUSTER - 500 LB	2	30
14	THRUSTER - 100 LB (4 CLUSTER ASSEMBLIES)	16	82
15	FILL VALVE - FUEL	1	
	PLUMBING, FITTINGS	1 SET	20
	VALVES (LISTED ABOVE)	1 SET	43
	CLUSTER MOUNTING HARDWARE (FROM LM)	4 SETS	25
	TOTAL WEIGHT		460 LB

Fig. 39 Schematic and Component Listing - Propulsion Subsystem

a. A CSM can be launched with a replacement Propulsion/Support Module attached to the docking ring. Several previous LMSC studies have verified the feasibility of this sub-mission. (Alternatively, a Space Shuttle vehicle could deliver the replacement.)

b. The CSM/PSM would rendezvous with the orbiting LTEP Module.

c. The depleted PSM would be released from the ATM Rack by RF command from the CSM. Pinpullers at four attach points would be actuated.

d. The CSM would push the replacement PSM into position on the ATM Rack Docking Structure. This Docking Structure would consist of a duplicate Apollo docking ring and drogue cone mounted rigidly on the ATM Rack and a mating probe mounted on the PSM end interfacing with the ATM Rack.

   If the PSM replacement principle were adopted, the ATM Rack – PSM interface would require addition of the mechanical docking devices and a quick-disconnect electrical connector panel.

3.4.3 Electrical Power Subsystem

Analysis of electrical power requirements were conducted for both Cluster-attached and Independent flight modes. It was determined that the ATM Rack electrical power system (a solar array-battery system) is quite adequate for the LTEP operations; in fact, the power sources (solar arrays and batteries) can be reduced 50 percent and still provide adequate margins for both flight modes. The derivation of requirements and a description of the subsystem elements and functions are summarized in this section. A more detailed description is provided in Appendix C.

3.4.3.1 Operational Power Requirements. In the analysis of requirements the various mission constraints regarding dark and light cycles and relative sun position were inspected. Also the AAP Dry Workshop Cluster electrical power needs were analyzed and used as the minimum requirement.

a. Orbit Restrictions and Solar Array Movement – The LTEP telescope must point to any target in the universe except that the line-of-sight may not intersect a cone generated about the earth-sun line with a 45 deg half-angle (see Fig. 40). After acquisition of the stellar field, the spacecraft/telescope will remain locked-on (inertially stabilized) to the target for periods from a few hours to about four days (multi-orbits).

   The orbit plane of the LTEP system will be rotating relative to the sun line at a rate of about 7.56 deg per day, completing a 360 deg rotation cycle in $\frac{360}{7.56} = 47.6$ days. The angle of the sun with the orbit plane will vary from 58.5 deg to zero in about 12 days, from zero to -11.5 deg in the next 12 days, back to zero in 12 days, and then back to 58.5 deg in 12 days (complete cycle equal to 47.6 days)

   The spacecraft/telescope, although in the orbit plane, will have a fixed inertial position relative to the sun during a single stellar-pointing period and, therefore, will present a single solar array orientation during this

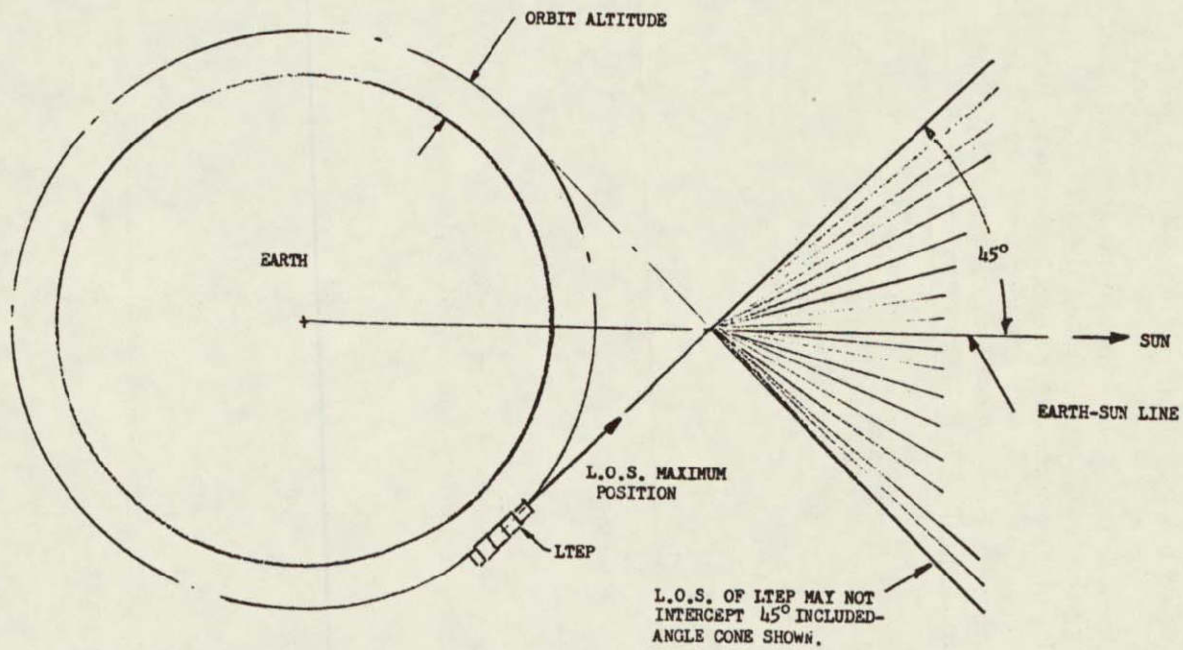


Fig. 40 Viewing Limits of LTEP

period. Alignment of solar arrays with the sun, if required, will be accomplished prior to extra-fine optical pointing (to prevent torque disturbances during steady-state stellar viewing).

During the cycling of the orbit-plane angle with sun line from zero to 58.5 deg, the time per orbit that the LTEP system is in earth's shadow varies from 25 minutes (for zero angle) to 36 minutes (for maximum angle); Fig. 41 contains the curve showing occulation time. The worst case, 36 minutes, has been chosen as the time that no sun energy would be available to the LTEP system solar arrays.

b. Basic Power Required for the Independent LTEP System – The continuous average power required for independent operation of the LTEP Module has been estimated to be:

CMGs		800 Watts
Telescope		250
LTEP Subsystem (Communication, Data Processing, Control, Propulsion)		450
Contingency		200
	Total	1700 Watts

The power requirements for the main user, the CMGs, are (from NASA/MSFC data on the Dry Workshop, Reference 7-22):

	Per CMG	Total
Bearing heaters (warmup) ($-60^{o}F$ to $50^{o}F$)	240 Watts	720 Watts
Bearing heaters (run) ($50^{o}F$ to $70^{o}F$)	48	144
Inertia-wheel runup (9 hours max.)	170	510
Inertia-wheel steady-state	56	168

The warmup bearing heaters are turned on prior to energizing inertia wheel drive; these require 720 watts input. The run bearing heaters are cut in when the temperature has raised to $50^{o}F$ and are intermittently switched on or off to maintain bearing temperature in the range of $50^{o}F$ to $70^{o}F$. Simultaneously, the inertia-wheel runup motors are energized; they require an average 510 watts. Total required during the runup is therefore $144 + 510 = 654$ watts. After the runup period (9 hours maximum) the steady-state load drops to $144 + 168 = 312$ watts. Thus, the 800 watts initial power for the CMGs is conservative and, in later system refinement and optimization, can probably be lowered and provide additional margins for telescope and spacecraft subsystem power.

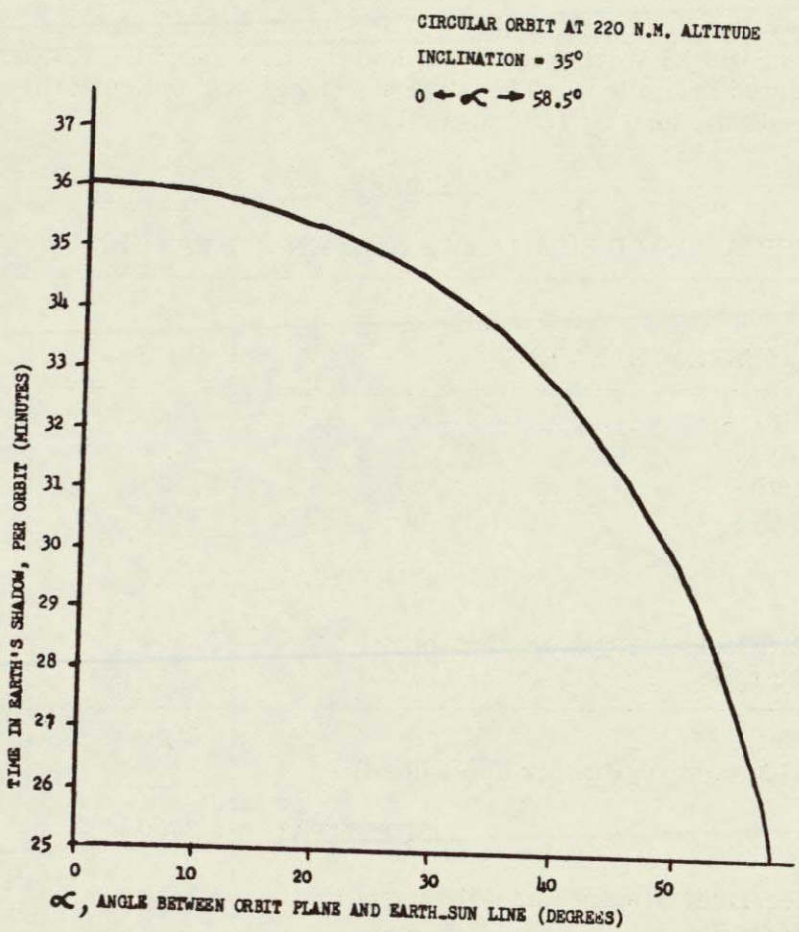


Fig. 41 Solar Occultation Time per Orbit

The power for operating optical system elements was set at 250 watts, utilizing an earlier estimate for experiment requirements. This number will require firming up in follow-on study as the electrical load profiles for optical system and experiment support become available.

The estimate of 450 watts for support of the various LTEP spacecraft subsystems is conservative. During stabilized periods of stellar-pointing, "maintenance" power will possibly drop to as low as 200 watts.

c. Power Required by Cluster/LTEP System — The electrical loads for the previous Saturn I Workshop (SIWS) and the New Saturn V Workshop (SVWS) are tabulated in Table 3. The ATM electrical system capability (3480 watts) exceeds the load by 1083 watts.

Table 3

ELECTRICAL LOAD SUMMARY - SATURN I VS SATURN V CLUSTER

SYSTEM ELEMENT	WATTS			
	SIWS		SVWS	
OWS (load)	1866		1509	
AM (load)	858		966	
MDA (load)	200		200	
CSM (load)	450		1100*	
SUBTOTAL	3374		3775	
OWS/AM Electrical System Capability	3700		3700	
Power Margin		326		(-75)
ATM (load)	3000		2127	
MDA (ATM control/display only) (load)	-		270	
SUBTOTAL	3000		2397	
ATM Electrical System Capability	3480		3480	
Power Margin		480		1083
Overall Cluster Power Margin		806		1008

*NOTE: The CSM load (1100 watts) may be divided between the ATM and the OWS/AM power supplies.

The Workshop/AM system has a negative margin of 75 watts, due to an increase of dormant CSM electrical load to 1100 watts (from a previous 450 watts). This higher wattage for the "dormant" CSM is a conservative estimate of the power required to keep the CSM in "semi-ready" status and allow shut-down on the CSM fuel cells (previously supplying 1800 watts).

The following illustrates the derivation of power requirements for the Cluster/LTEP system:

(1) The proposed modified Cluster loads will total 3700 watts:

OWS	1509 Watts
AM	966
MDA	470
CSM	755
Total	3700 Watts

(2) The ATM loads, with the LTEP, have been estimated as 1350 watts:

CMG's	800 Watts
Telescope	250
LTEP Subsystems (Control, Data Processing)	200
Contingency	100
Total	1350 Watts

The 755 watts shown for the CSM is lower than the 1100 watts estimated by NASA. However, an average of 390 watts will be available from the ATM electrical system, which will have a capacity output of 1740 watts (compared to load of 1350 watts). If required, this additional wattage can be transferred from the ATM to the OWS/AM electrical system thereby providing a total of 390 + 755 = 1145 watts to the CSM.

3.4.3.2 Standby Power Requirements. With the telescope and experiment electrical loads, except heaters, in a dormant state, the CMG's and Pointing Control system (in ATM Rack) holding a prescribed inertial attitude in orbit, and other LTEP subsystems dormant (except for ground station tracking communications link), the estimated electrical loads are:

CMG's (inertia-wheel steady-state)	168 Watts
CMG Bearing Heaters (run intermittently)	144
Telescope	20
LTEP Subsystems	200
Contingency	100
Dormant Total	632 Watts

This "dormant" total wattage required is considerably lower than the 1700 watts which has been selected as the operational average for the system. During system optimization studies (which should be accomplished in follow-on effort) reduction of the operational power may be desirable; using battery power exclusively for early peak loads may allow reducing the solar array size. Each of the solar arrays has 5 segments; removal of 1 or 2 segments can probably be accomplished without significant influence on the other parts of the system. Any reduction of this type in available solar array power should be delayed until all LTEP electrical loads have become relatively firm.

3.4.3.3 Electrical Subsystem Design. Following an analysis (Appendix C) of power requirements versus alternate system concepts for a single system compatible with both Cluster/LTEP and Independent LTEP operation, it was concluded that:

a. A solar array/battery system provides the most reliable approach.

b. Fixed solar arrays, although theoretically feasible for the LTEP, would add a very large amount of weight to the system (multiple quantities of existing arrays). Fixed arrays would not be feasible for the OWS application because of array overlays and vehicle/array shadowing.

c. Single-axis movable arrays for both the LTEP and the Cluster, combined with rotation of the Cluster/LTEP or the LTEP around the telescope line-of-sight, provides universal aiming of the arrays with surfaces normal to the sun-line with any telescope stellar-pointing attitude.

d. Placement of solar cells on both sides of solar arrays would increase weight of the arrays. Conversely, rotating each array ±180 deg, in lieu of ±90 deg, would allow use of single-side solar cell application.

e. Estimated electrical loads can be satisfied by use of two ATM solar arrays (in lieu of the present four) and the existing two OWS solar array wings.

The various components of the ATM electrical system have been examined and are rated as compatible with the LTEP operational requirements. The ATM electrical system planned for use on the Dry Workshop Cluster can be used, with deletion of 50 percent of the solar arrays and batteries and associated minor modifications. Described following are the existing Dry Workshop Cluster system, proposed modifications thereto, and the proposed independent LTEP electrical subsystem.

a. AAP Cluster Electrical System. The Saturn V Workshop Electrical Power System (EPS) comprises (1) the ATM solar array/battery system, (2) orbital Workshop/Airlock Module (OWS/AM) solar array battery system, and (3) associated control and distribution networks. A simplified block diagram is shown on Fig. 42.

   The OWS/AM electrical system supplies 3700 watts average from two solar arrays of 600 ft^2 each and eight Power Conditioning Groups, each comprising a battery charger, a bus voltage regulator, and a battery. The lifetime rating of this system is being increased to nine months (was rated two months) by additional testing and component selection.

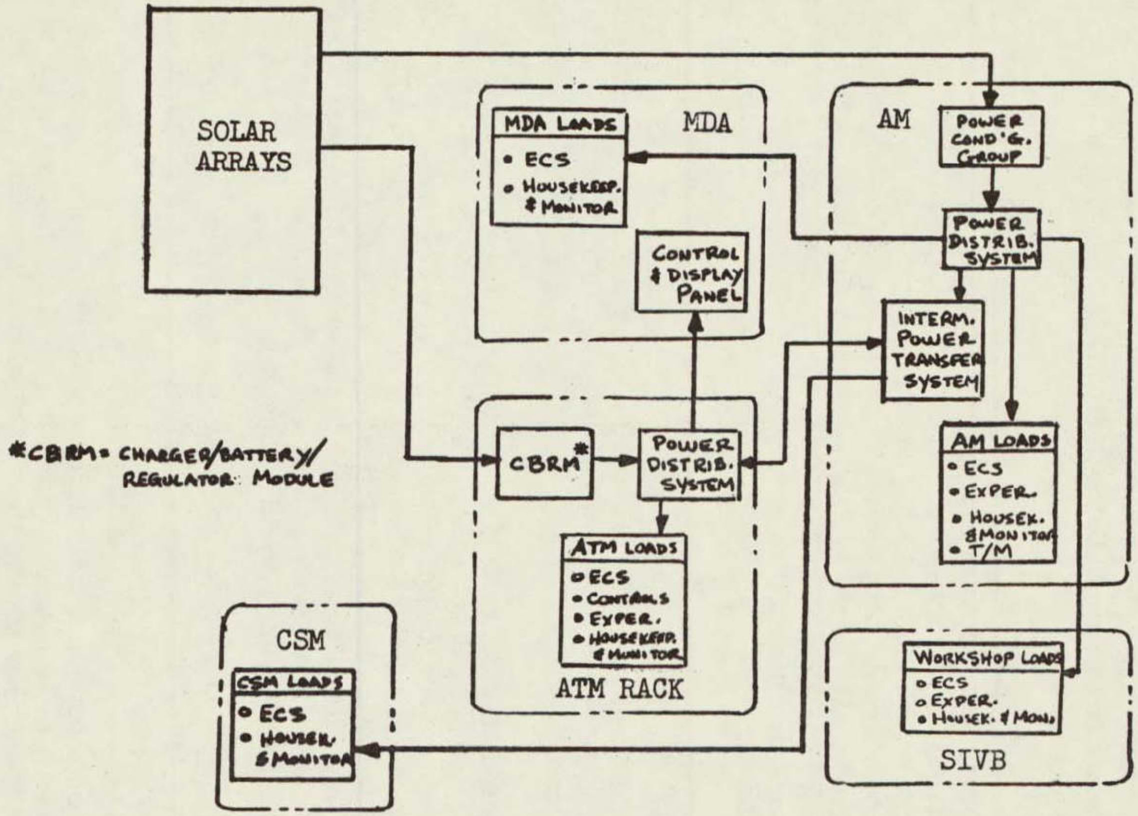


Fig. 42 Block Diagram of Electrical Power System - Saturn V Workshop Cluster

The ATM electrical system supplies 3480 watts average from four solar arrays of 300 ft^2 each and 18 charger/battery/regulator modules (CBRM's). Lifetime of the system is being extended to nine months (from two months). The ATM power system supplies redundant power to ATM loads simultaneously through diode isolation so that single-point failure will not prevent normal operation of any load package. A bidirectional power transfer up to 2500 watts can be made between OWS/AM and ATM power systems for contingency operations.

Figure 43 is a scale drawing of the Cluster/ATM showing the relative size and location of the solar arrays. The four arrays on the ATM are extended to a fixed position as shown. The OWS solar arrays are stowed in longitudinal fairings on the SIVB cylinder during launch and ascent and are unfolded after orbit position has been attained. Initially planned for rotation about a forward hinge axis as shown, these two arrays will be locked in the central position for the Dry Workshop Cluster operation with the ATM (NASA/MSFC indicates that the rotating mechanism can be re-installed in the Dry Workshop).

The ATM arrays each consists of five segments, each approximately 8 feet square. Each panel in the array is 20 x 24.6 inches. The OWS arrays are about 313 inches in the fore-aft direction and are stowed in fairings, each of which is 13 x 48 x 397 inches long. The OWS array panel size is 27.1 x 30.1 inches.

b. Cluster Electrical System Modification. The only change electrically to the Cluster electrical systems for LTEP application is deletion of two items and addition of disconnects. Two of the four ATM solar arrays will be deleted, thereby reducing the system output from 3480 watts to 1740 watts. Nine of the 18 batteries in the ATM system will also be deleted. Additionally, a quick-disconnect must be added in the electrical hard-line between the ATM Rack and the new Cluster swing-links (to accommodate automatic separation of the LTEP Module from the Cluster).

A simplified block diagram of the Cluster/LTEP electrical power system is shown on Fig. 44. A more detailed discussion of changes (omissions to) in the ATM electrical system is included in paragraph c.

Because the solar array surfaces must be essentially normal to the sun-line to develop rated power output it is necessary in the stellar-pointing mode to orient the arrays toward the sun mechanically after a star-field target has been acquired. A single-axis (rotational) movement of the arrays on both the ATM and the OWS, combined with a roll maneuver (about the telescope LOS) of the Cluster/LTEP will provide repositioning of the array surface to a position normal to the sun-line.

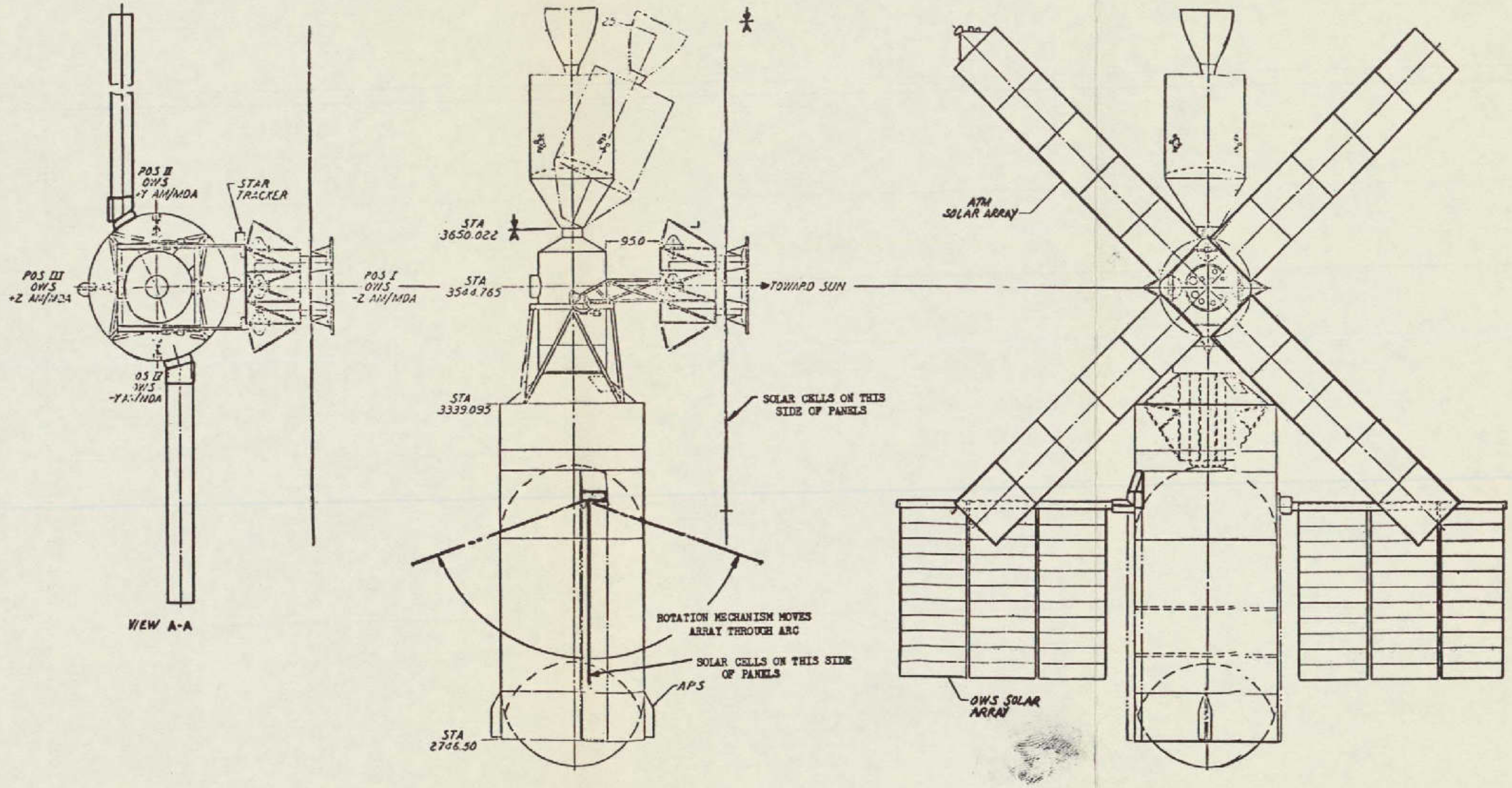


Fig. 43 Dry Workshop Solar Arrays

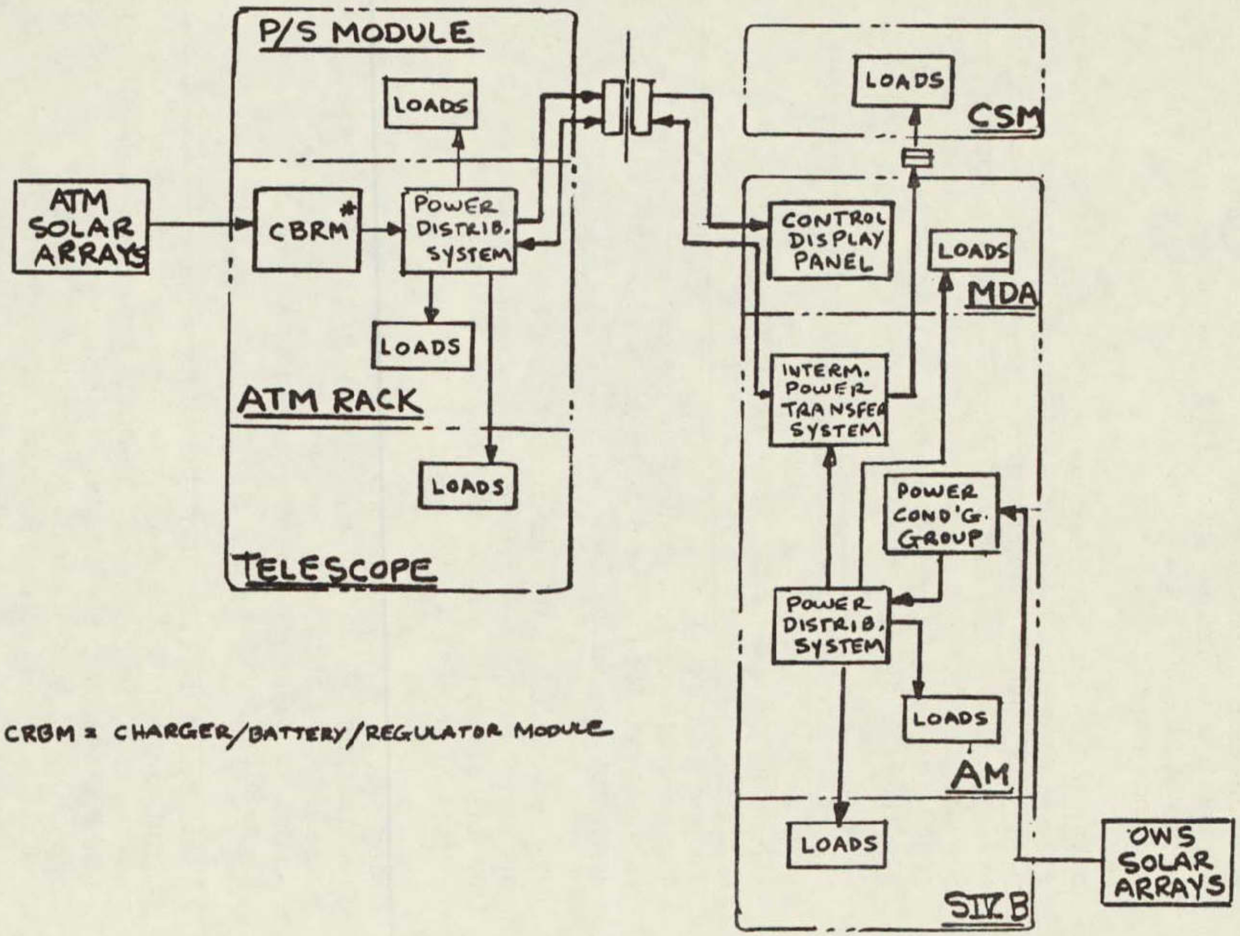


Fig. 44 Cluster/LTEP Electrical Block Diagram

To allow usage of the existing ATM and OWS solar arrays, which have solar cells on one side only, a full 360 deg rotation of the arrays is required to accommodate all possible inertial attitudes of the Cluster/LTEP. The existing rotation mechanism on the OWS solar arrays can probably be modified to provide the 360 deg rotation. The two rotatable ATM solar array wings are shown in Fig. 45.

c. Subsystem Functional Characteristics. The block diagram illustrated in Fig. 46 shows the basic elements of the LTEP electrical subsystem. The power distribution box and CBRM's are mounted on the ATM Rack. The pyrotechnic batteries and distribution box are mounted within the Propulsion/Support Module. The electrical subsystem will have an average output of 1740 watts, nominally at 38 volts dc. A weight breakdown is given in Table 4. The characteristics of the elements are:

(1) Solar Arrays. The two solar arrays utilized are identical to two of the four used on the existing Apollo ATM Rack. Each array is approximately 105 inches wide and 525 inches long in the displayed position and comprises five segments. The two arrays are 180 deg opposed as shown in Fig. 45. The stowed package size for each array is approximately 8 ft x 8 ft x 1 ft. The current extension mechanism is considered adequate. A minor modification is required at the inboard end of each array to adapt it to the newly-added rotation mechanism.

The two current OWS solar arrays (coupled with batteries) have an average output requirement of 3700 watts at end of life (nine months). This includes factors of battery efficiency, line losses, earth shading, and 10 deg misalignment of solar arrays (away from plane normal to sun-line).

Similarly, the ATM solar arrays (4) and associated batteries have an output requirement of an average 3480 watts at end of life (nine months) including all aforementioned reduction factors. These ATM arrays were initially designed for 24-month operation and can probably attain this with the same degradation percentage.

Table 5 lists the characteristics of the ATM and OWS solar arrays. It is significant to note that NASA has made a change to the OWS solar cell and cover glass, changing from an initial 0.012-inch thick silica (fused-quartz) to a 0.006-inch thick "standard" glass; the changes reduced the potential life capability of the cells from 24 months to 9 months. The ATM solar cells are the higher-performance type and have an estimated life in excess of 24 months. The primary degradation of the micro-glass cover results from darkening because of UV exposure (estimated to be about 5% to 10% degradation in an initial 9-month period).

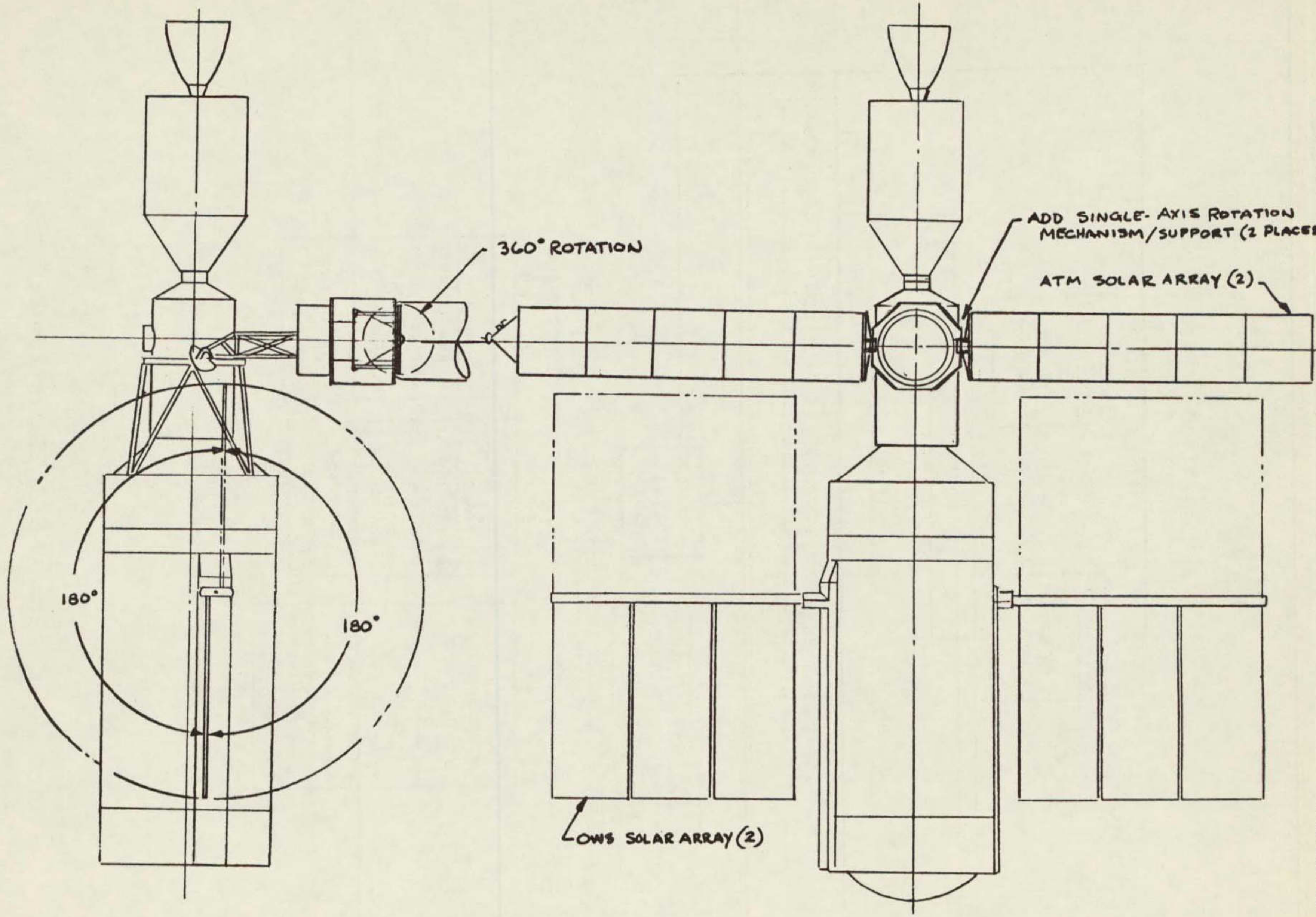


Fig. 45 Cluster/LTEP Solar Array Arrangement

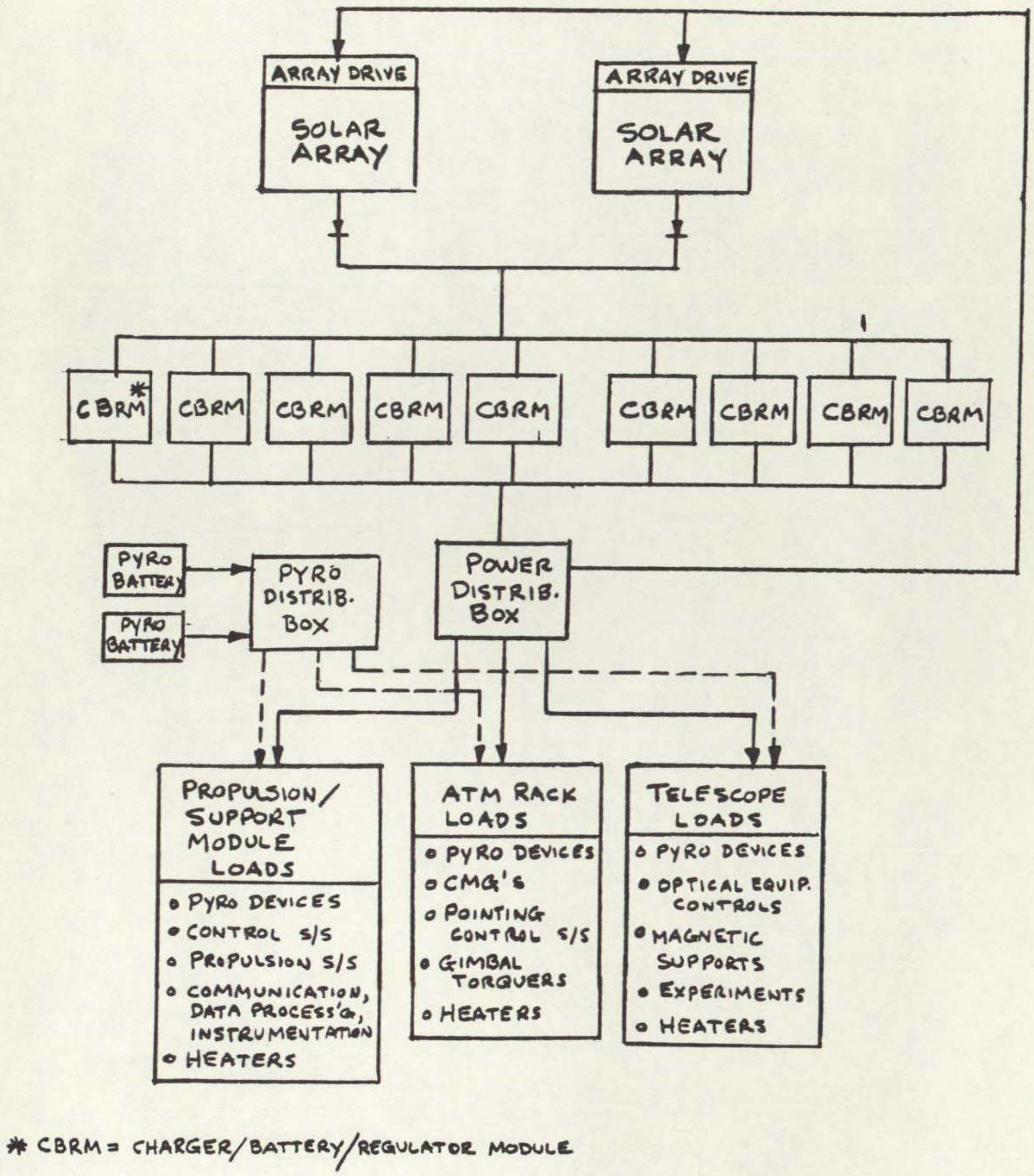


Fig. 46 Block Diagram of LTEP Electrical Power System

Table 4

WEIGHT BREAKDOWN - LTEP ELECTRICAL POWER SUBSYSTEM

ATM Rack Electrical		1636 lb
*Charger/battery/regulator modules (9)	855 lb	
*Control distributors (2)	51	
*Voltage supply measurement (2)	5	
*Measurement distributors (2)	51	
*Selector switch (2)	40	
*Aux. power distributor	50	
*Main power distributor	35	
*Power transfer distribution	100	
*Transfer assy.	50	
*J-boxes (12)	24	
*Control/display logic distribution	50	
*Cabling - rack	275	
*Cabling - gimbal	50	
Solar Array Electrical		2235 lb
*Solar arrays (2)	2035 lb	
Rotation mechanism (2)	200	
Propulsion/Support Module Electrical		188 lb
Pyro (aux.) batteries (2)	120	
Pyro distribution assy.	20	
Voltage controller/regulator	18	
Cabling	30	
Telescope Electrical		10 lb
Total Electrical Subsystem		4069 lb

*NOTE: Items identified with an asterisk (*) are from the current Apollo Cluster ATM electrical system.

Table 5

CHARACTERISTICS OF ATM AND OWS SOLAR ARRAYS

Characteristic	ATM Solar Array	OWS Solar Array
Area	1200 ft^2	1200 ft^2
Weight (approx.)	3800 lb	3800 lb
Honeycomb panel		
Skin	0.015 in	0.008 in
Core (honeycomb)	3.1 lb/ft^3	3.1 lb/ft^3
Panel thickness	0.5 in	0.38 in
Cover glass (for cell)	0.012 in Silica (fused quartz)	0.006 in Micro sheet (bottle glass)
Watts/lb (solar panel)	6 watts/lb	11 watts/lb
Normal incident output (at end of estimated life)	10.6 KW	11.9 KW
Solar cell		
Efficiency	9.8 minimum (10.25 avg.)	10.3 minimum (10.6 avg.)
Base material	10-ohm CM	1-ohm CM
Panel operating voltage	38 volts	49 volts
Array articulation	None	1 Axis
Life	*9 months (reqd.) *24 months (actual)	9 months (actual)

*NOTE: 0.012-inch cover glass plus 10-Ohm CM cell has estimated life expectancy of 24 months or longer. Current AAP Cluster requirement is 9 months for both ATM and OWS solar arrays.

The ATM arrays are conservatively-sized for the electrical loads involved. The solar arrays for the LTEP system must have a maximum output at end-of-life (at least two years) of 3240 watts; 1500 watts allocated to battery recharge and 1740 watts to electrical loads. An LMSC calculation indicates that a solar array end-of-life output to satisfy the ATM electrical system requirements would be sized to output approximately 6.6 KW; the NASA array equivalent output is 10.6 KW (for four wings). Because this figure assumes a solar cell degradation of about 10 percent, it is probable that this array could operate for an additional 4 years with an additional accumulative 10% degradation. In other words, the arrays (4) would output approximately 9.5 KW at the end of five years; two arrays would output 4.75 KW.

A 360 deg rotation mechanism is required on each array at the attachment to the top frame of the ATM Rack. The centerline of rotation would be perpendicular to and intersecting the centerline (line-of-sight) of the telescope. All actuation of the arrays for alignment with sun-line will be accomplished after coarse-pointing stellar target acquisition and prior to steady-state optical pointing. The array rotation, coupled with rotation of the LTEP vehicle about the telescope line-of-sight, will provide solar array aiming at the sun-line for any orientation of the vehicle.

(2) Batteries. The batteries for LTEP usage are required to have an output total of 137 ampere-hours if the discharge depth maximum is limited to 20 percent with an electrical load of 1740 watts:

$$\frac{1740 \text{ watts} \times \frac{36}{60} \text{ hour}}{0.20} = 5200 \text{ wh}$$

for a battery with 38 volt output,

$$\frac{5200 \text{ wh}}{38\text{v}} = 137 \text{ ampere-hour}$$

Utilizing the present ATM 20 ampere-hour battery, seven batteries would be required to satisfy the load. Conservatively, nine batteries have been selected (of the total 18 on ATM). The batteries are rechargeable, non-venting, 24-cell supplied by General Electric. Each battery is part of a Charger/Battery/Regulator Module (CRBM). Additionally, for the Cluster-attached operation, the Airlock Module (AM) includes eight batteries. Each is rated at 33 ampere hours with 30 cells and output a nominal 49 volts dc. Supplier is Eagle Pitcher.

A more detailed description of the LTEP electrical power requirements is contained in Appendix C.

3.4.4 Attitude Control System

The attitude control system (ACS) proposed for the LTEP system is essentially the same as that used on the AAP Cluster in conjunction with the ATM solar telescope. The LTEP system requires a change in spatial sensors; additional star trackers must be substituted for the sun sensor of the ATM solar-pointing system. Otherwise, the control moment gyros (CMG's) and Pointing Control System of the ATM will be used intact. Attitude control thrusters will be mounted on the SIVB in the Cluster-attached mode and on the LTEP Propulsion/Support Module in the Independent mode.

The modes of control envisioned for the LTEP system are:

- Coarse-Pointing - Total vehicle positioning accomplished by thrusting with the attitude control thrusters.

- Fine Pointing - Vernier stabilization of the total vehicle by CMG's combined with narrow-band pointing of telescope (gimballed mass) by the ATM Pointing Control System.

- Extra-fine (Optical) Pointing - Vernier optical element adjustment within the optical system using the telescope as a base.

The reference axes used are illustrated in Fig. 47. The pointing/stability requirements for the spacecraft, the estimated performance of the control system (excluding the optical element controls), and a description of the proposed control subsystem are included in the following paragraphs.

3.4.4.1 Pointing and Stability Requirements. The LTEP system, including the optical system, has the objective of continuous-state pointing to a stellar target for several hours up to as long as several days and holding the line-of-sight to within ±0.01 arc sec of the theoretical target. The extremely close-tolerance pointing will be accomplished by the optical system which is mounted on the telescope structural base. The pointing accuracy required of the gimballing telescope structure is at least ±2.5 arc sec. For certain of the LTEP experiments improved pointing accuracy over and above the present ATM accuracy of 2.5 arc seconds will be available as a result of redesign.

The inertial characteristics of the LTEP Module and the Cluster/LTEP are provided and the external forces acting upon the gimballed telescope are discussed following.

a. Inertial Characteristics of Telescope and Platforms. The weights and moments of inertia of the elements of the orbiting systems are listed in Table 6. The values given for the Cluster/ATM include the ATM Rack, four ATM solar arrays, and the gimballed solar telescope/spar. The reduction of the ATM Rack weight, the removal of two of the four ATM solar arrays, and addition of the LTEP Propulsion/Support Module adds a net 2725 lb to the on-orbit mass. However, the mass distribution is changed considerably by the deletion of the two solar arrays. For purposes of preliminary estimates and evaluation, therefore, the moments of inertia of the Cluster/ATM were used for the Cluster/LTEP.

b. Forces causing Movement of the Telescope Gimballed Mass. Forces and torques acting upon the telescope as a gimballed mass were calculated. The solar pressure provides a torque of 6.2×10^{-4} ft lb about the gimbal pivot; aerodynamic forces account for 2.95×10^{-2} ft lb torque; and gravity-gradient torques reach a maximum of approximately 9.3×10^{-2} ft lb four times per orbit. Since there are not any significant magnets or large wire coils within the telescope assembly, the magnetic torque is estimated to be essentially zero. Separate analysis is required for the magnetic suspension system.

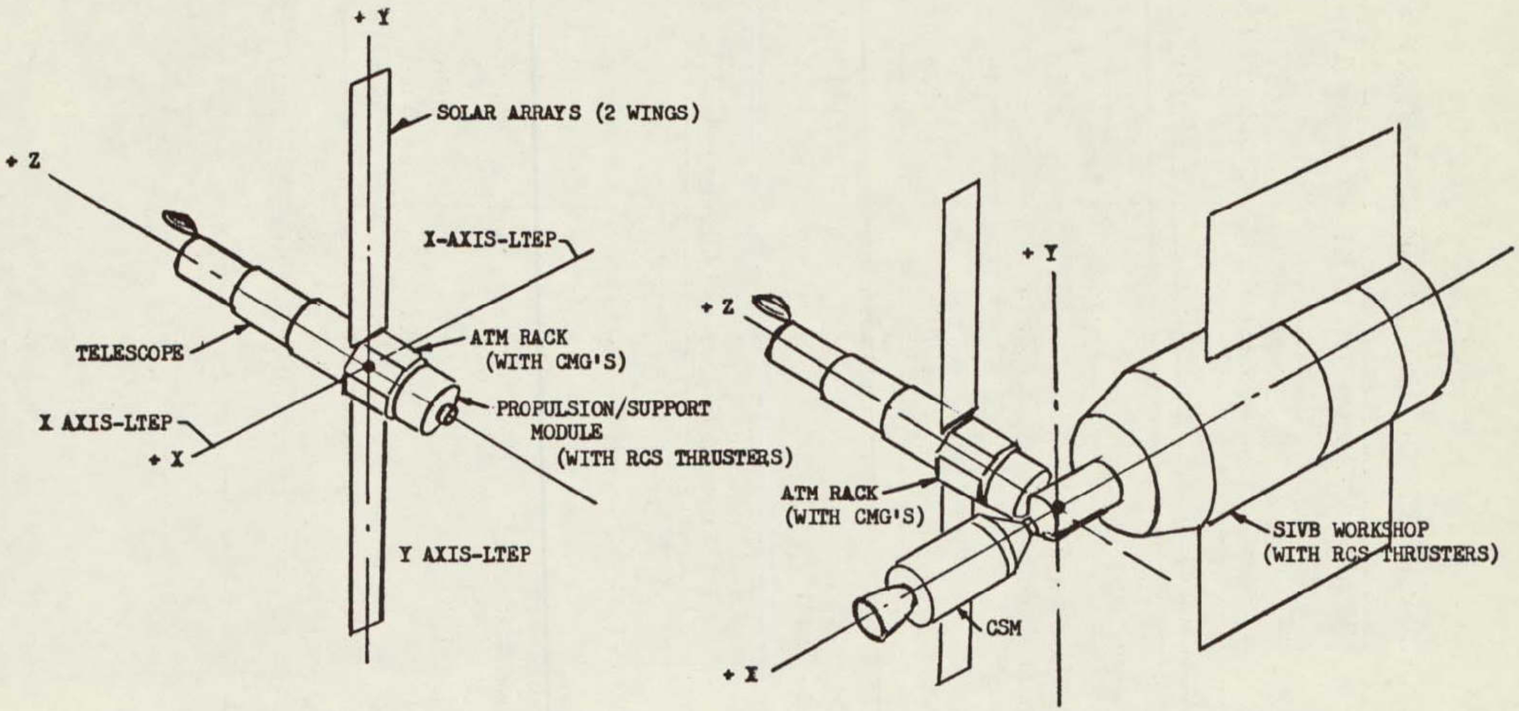


Fig. 47 Configurations and Reference Axes of Cluster-Attached and Independent Modes

Table 6

WEIGHTS AND MOMENTS OF INERTIA OF LTEP SYSTEM ELEMENTS

Weights of Cluster and LTEP Elements (lb)

	Cluster/ATM	Cluster/LTEP	Independent LTEP
Cluster (less ATM Rack, solar telescope/spar, and solar arrays)	99160	99160	-
ATM Rack	9235	-	-
ATM Rack (Modified for LTEP)	-	8150	8150
Solar Telescope and Spar*	5535	-	-
LTEP Telescope*	-	8096	8096
Propulsion/Support Module	-	3965	3965
ATM Solar Arrays	4070	2035	2035
Cluster/ATM Total	118000 lb		
Cluster/LTEP Total		121416 lb	
LTEP Module Total			22256 lb

Moments of Inertia (Slug-ft^2)**

INDIVIDUAL ELEMENT	I_X	I_Y	I_Z
LTEP Telescope	23278	23278	1388
ATM Rack (modified for LTEP)	5683	5948	7668
Propulsion/Support Module	1189	1192	1961
Solar Arrays (2)	27761	27761	55261
LTEP Module Total	66115	66378	66290
Cluster/ATM Total	1182000	7130000	7460000
Solar Telescope and Spar	1107	2464	2479

Notes: *Items designated are the gimballed masses.
**Moments of inertia are about the center-of-gravity of the element named.

(1) Solar Pressure Torque. Solar pressure will provide a torque about the telescope gimbal points. This torque will vary dependent upon the frontal exposure (toward the sun) of the spacecraft/telescope. Assuming a maximum condition, the projected area of the exposed portion of the telescope tube (protruding outside of the ATM Rack) would be approximately 260 ft^2. The center-of-pressure is about 17 ft from the center of rotation. The solar pressure was estimated at approximately 1.4×10^{-7} lb/ft^2 for a 50 percent reflection condition.

Therefore,

$$\text{Torque} = (1.4 \times 10^{-7})\,(260)\,(17)$$

$$= 6.2 \times 10^{-4} \text{ ft. lbs}$$

(2) Aerodynamic Torque. LMSC analytical historical data indicated that for a spacecraft at a similar altitude, 150 ft^2 of frontal area with a center-of-pressure about 3 ft from the center-of-gravity, the aerodynamic torque was 3×10^{-3} ft. lb. Ratioing these values to the LTEP equivalent values results in an estimated aerodynamic torque of 2.95×10^{-2} ft lb.

(3) Gravity-Gradient Torque. The formulae used for gravity-gradient torques in terms of orbital rate are:

$$\text{Pitch : Torque (ft-lb/radian)} = 3\omega_o^2 (I_X - I_Z)$$

$$\text{Roll : Torque} = 4\omega_o^2 (I_Y - I_Z)$$

$$\text{Yaw : Torque} = \omega_o^2 (I_Y - I_X)$$

The term ω_o = orbital rate = $\frac{2\pi \text{ rad}}{5400 \text{ sec}}$ or 1.16×10^{-3} rad per sec. By inspection, the maximum torque will occur in the "roll" condition and when the centerline of the telescope is at a 45 deg angle with the line through the gimbal center and the center of earth.

From Table 6:

$$I_Y = 23278 \text{ slug-ft}^2$$
$$I_Z = 1388 \text{ slug-ft}^2$$
$$I_Y - I_Z = 21890 \text{ slug-ft}^2$$

Therefore:

Torque rate $= (4)\ (1.6 \times 10^{-3})^2\ (21890) = 0.118$ ft lb/rad,

or

$$\frac{0.118}{57.3} \text{ ft lb/deg}$$

Therefore the approximate maximum torque at 45 deg equals
$\frac{0.118}{57.3} \times 45 = 0.093$ ft lb

3.4.4.2 Control System Performance Analysis. The two basic elements of the spacecraft control system are the attitude control thruster subsystem and the ATM Pointing and Control System. Their performance characteristics were examined; results are as follows:

a. Attitude Control Subsystem. Because of the long-duration operating period of the LTEP system, it has been assumed that ACS usage would be limited to:

(1) Initial acquisition of star-field target (coarse pointing).

(2) Orbit maneuvers for attitude correction.

(3) Backup only for CMG desaturation maneuver (normal mode utilizes earth gravity-gradient torques).

Use of the ACS thrusters for any continuous period of pointing would rapidly deplete the usable propellant quantity of approximately 500 lb carried by the Propulsion/Support Module for the Independent Mission (i.e., the Titan IIIC LTEP) and similarly deplete the propellant planned for the SIVB in the Cluster/ATM or Cluster/LTEP missions. It is planned, therefore, that the ACS thrusters will be deactivated when the ATM Pointing and Control System is operating (following the coarse-pointing maneuver).

Attitude control coarse-pointing accuracies can be held as small as ±0.3 deg for the AAP Cluster. This is a lower limit and will cause a large usage of propellant if maintained for periods longer than initial starfield acquisition. The angular rate of movement of the AAP Cluster is 0.3 deg per sec maximum in any axis.

The angular movement rate for the Independent LTEP system can range between 0.2 and 1.0 deg per sec. The deadband amplitude limits can be held to about ±0.3 deg in any axis. The maximum possible limit should be utilized, however, in order to lessen the average propellant usage rate. It is proposed that ±1.0 deg be used as the conceptual design limit for the ACS pointing capability with an angular rate of 1 deg per sec maximum.

b. ATM Pointing and Control System (PCS) Characteristics. The ATM PCS comprises the two basic elements:

(1) Control Moment Gyro (CMG) Subsystem – Provides pointing and control of the total Cluster/LTEP and dynamic control about the Z (roll) axis.

(2) Experiment Pointing Control (EPC) Subsystem – Provides fine pointing and control of the telescope gimballed mass about the X and Y axes and open-loop crank-around for roll-positioning about the Z axis.

Table 7 is a summary tabulation of the ATM control characteristics. The maximum fine-pointing control range of the line-of-sight for the ATM telescope is ±20 arc min with the solar disc limits estimated at ±16 arc min. The LTEP equivalent range in the planes including the X and Y axes is ±30 arc min (the gimbal angle range is ±2 deg). The basic pointing capability has been separated from the "stability" capability (the latter is a lower value). Because the current ATM specifications limit the "stability" mode to 15 minutes of time, it has been assumed, conservatively, to use the basic pointing accuracies in this preliminary assessment of LTEP accuracies.

The EPC subsystem does not include a vernier roll-position fine-pointing control element. All roll corrections are accomplished by torquing the roll gimbal motor drive and by CMG movement of the total Cluster/LTEP or the total LTEP Module. The initial analyses of the CMG characteristics were reportedly based on a rigid-body assumption. The current NASA analysis, borne out by simulation runs, indicates that the ATM Cluster is a flexible-body vehicle having very small movements at low frequencies. To damp the unknown structural bending modes, NASA added a 4th-order filter for each of the three axes, placed in the CMG control circuit just upstream of the CMG input. It is reported that this filter not only reduces the effects of flexible-body inputs but also attenuates most, if not all, of the sun sensor and rate gyro noise. The frequency output from the CMG control loop is very low, 0.08 to 0.10 cps. The CMG input to the EPC loop appears like a large stationary body because of this very low frequency. The EPC loop, because of an experiment requirement to settle-out all disturbances within 10 seconds time period, has been designed with higher frequency characteristics, 2.0 to 2.5 cps.

Two-sigma values for the various EPC loop errors have been summed; they total ±1.77 arc sec pointing accuracy in the planes containing the X and Y axes. No transient disturbances are assumed in the pointing accuracy calculations. For a brief time period of 15 minutes (which probably can be extended), a root-sum-square of the errors accruing from disturbances external to the control loop equals ±0.63 arc sec. Primary transients assumed to be acting during the "stability" phase include ±0.2 arc sec for astronaut wall push-off, ±0.5 arc sec for thermal gradient, and ±0.3 arc sec for rack-to-experiment wire bundle creep.

Table 7

ATM CONTROL CHARACTERISTICS

Pointing Accuracy and Stability (arc sec)*

About Axis	Requirements				2σ Estimated			
	CMG		EPC		CMG		EPC	
	Pointing	Stabil.	Pointing	Stabil.	Pointing	Stabil.	Pointing	Stabil.
X	±240	±540	±2.5	±2.5	±160	±215	±1.77	±0.63
Y	±240	±540	±2.5	±2.5	±160	±345	±1.77	±0.63
Z (roll)	±600	±450	**	**	±38	±300	**	**

Error Sources

Subsystem	Pointing Uncertainties	Stability
CMG	Roll readout and positioning errors	Crew disturbances
	Various electronic gain, null offset, and drifts	
EPC	FSS null accuracy	Amplifier drift
	Computer	Thermal gradients
	FSS readout resolution	FSS short term effects
	Rate gyro	Wire bundle creep
	Gimbal wire torque	Crew disturbance (small)

Manual Control of FSS Loop (via actuator movement of prism to offset position)

• Range	±20 arc min
• Rate – near offset = zero	±135 arc sec/sec
• Rate – near offset = 20 arc min.	±76 arc sec/sec

*Stability limits apply over a continuous 15 minute time period
**EPC subsystem has no closed-loop circuit for roll control; CMGs provide roll control about Z axis

NOTE: Data from Reference 7-21

c. Disturbances and Effects. Crew movement is a primary disturbance in all configurations. However, in the Cluster-coupled mode, the influence is considerably lessened by placement of the telescope "operator" in the Cluster rather than in a compartment adjacent to the ATM Rack. Not only does the Cluster inertia attenuate a large portion of the initial disturbance, but the mechanical connections between the Cluster and the ATM Rack and between the ATM Rack and the telescope structure act as attenuating springs in the structure system. In the Independent operating mode, crew disturbances (in the MOTEL) are transferred directly to the CMG/EPC/gimbal stability loops.

Regarding crew movement, it is proposed that the following data, excerpted from a recent NASA document be used: "The effect of crew-motion disturbances was nearly negligible; the most significant being ± 0.2 arc sec position displacement as a result of astronaut wall pushoff disturbance." This conclusion resulted from analysis of a condition wherein an astronaut would push off one wall of the Cluster and 9.5 seconds later would impact the opposite wall. The maximum forces or torques would be attained 1.5 seconds after pushoff or impact.

It is also apparent that the LTEP coupled to the Space Station would be influenced primarily by the space station mass movements but to a much lesser degree by the crew movements within the Space Station. Further analysis will be necessary in this area in the future as the basic platform stability of the Space Station is determined.

Solar array positioning will be accomplished during or after the coarse-pointing maneuver and prior to the start of the optical system lock-on viewing period. As previously mentioned, the ACS thrusters also will be deactivated in the extra-fine pointing mode. Mechanical disturbances, other than astronaut-created, will be limited to the low-frequency torques applied to the vehicle or to the gimballed telescope by gravity-gradient, aerodynamic and solar pressure forces, and by the CMGs. Electronic disturbances may be from the output of the rate gyros and acquisition sensors in the control loop. The latter are reported to be filtered out effectively by a 4th order electronic filter upstream of the CMG input in the control circuitry.

In all cases, the current ATM control system and gimbal characteristics have been used in study of the LTEP problems. It is not possible readily to "tailor" the ATM system response to lower frequencies or amplitudes for greater adaptability to the LTEP system. However, the electronic componentry probably could be modified to provide lower frequency outputs and possibly with reduced amplitudes. No investigation has been made of the extent of modification required; however, it is a reasonable assumption that although the physical changes in the electronics might be fairly simple, a group of electronic packages would probably require at least partial requalification. This is an area to be resolved at such time as the specific modifications are determined to be desirable and feasible.

d. CMG Momentum Dumping. It is possible to dump or desaturate the CMGs by periodic firing of the RCS thrusters of the coarse-pointing control system. This method requires a considerable quantity of propellant over a long period of orbit operation. An alternate method currently proposed for use with the ATM Cluster is to desaturate using earth's gravity gradient force field.

There is a per-orbit momentum buildup in the CMGs as a result of gravity gradient, aerodynamic, and other torques. If periodic desaturation were not provided, the CMG would be saturated for progressively larger portions of an orbit after the first orbit. The axis of saturation would be roughly the X axis; after complete saturation, the CMG would not compensate for a disturbance torque about the axis of saturation. It is planned to periodically roll the cluster about the Z axis (sun-pointing) to minimize the momentum accumulation. The preventative maneuvering is probably not acceptable for LTEP stellar pointing. However, the proposed CMG desaturation technique appears adaptable to LTEP: the saturation effects are nullified periodically (by maneuvering the Cluster about two axes during either the night side or the day side of the orbit) by producing controlled bias torques employing rectified components of the gravity gradient torques encountered.

e. Net Movement of Telescope. The gimballed mass of the telescope, attached rigidly to the ATM Rack, will be moved to the following amplitudes and at amplitudes and at the frequencies noted (these are the net outputs of the ATM control system):

X Axis	Amplitude	±1.77 arc sec
	Freq.	2.0 to 2.5 cps
Y Axis	Amplitude	±1.77 arc sec
	Freq.	2.0 to 2.5 cps
Z Axis (Roll)	Amplitude	±38 arc sec
	Freq.	0.08 to 0.10 cps
	Rate	0.35 to 7 deg/sec

f. Improved Platform Stability. Because of the non-match of the current ATM control system to LTEP stellar pointing requirements, it may be desirable to propose a new, or at least modified, fine-pointing control system (CMGs plus gimbals) for the LTEP. Further detailed analysis of this approach is proposed if the current operating characteristics of the ATM control system force undesirable complexities into the LTEP optical control system. Detailed analysis of the electronic functions of the current system and potential modification to LTEP-compatible amplitudes and frequencies are recommended. The development of spectrums combining amplitudes and frequencies or optimization of system characteristics to lower the frequencies will require considerable additional analysis.

Because of the large influence of crew movements on platform stability (particularly in the Independent mode wherein the LTEP is not attached to the Cluster nor to the Space Station), long-term stellar pointing operations will possibly require (1) unmanned operations, (2) cooperative (relatively stationary or in sleep-cycle) crew, or (3) a magnetically decoupled telescope mount.

The current ATM control system was based on a requirement to reach null from a maximum disturbance amplitude within 10 seconds. If this elapsed time to settle out is lengthened the frequency of the X and Y axis movements can be lowered from the estimated 2.5 cps.

3.4.4.3 Control Subsystem and Operation. The attitude control system proposed for the LTEP mission comprises the same componentry as the AAP Cluster/ATM system. Because the ATM solar telescope is aimed toward the sun, sun sensors (2) and a single star tracker are used for sensing in the acquisition mode. A proposed modification for the LTEP mission utilizes a fixed star sensor and a gimballed star tracker mounted on the ATM Rack. A precision target star sensor is mounted on the gimballed telescope. Figure 48 schematically illustrates the arrangement. The telescope gimbal is caged in the null position until the ATM Rack control system brings the target star into the field-of-view of the precision sensor on the telescope tube.

The basic block diagram for the latest Dry Workshop Cluster control system is illustrated on Fig. 49 as extracted from a NASA report (Reference 7-22). The interface of the ATM Rack with the Workshop is shown. Similarly, a flight control electronics package would be installed in the LTEP Propulsion/Support Module with the ACS thruster assemblies and interface with the ATM control system. A functional schematic of the control system is shown on Fig. 50. In the Cluster-attached mode, the block marked "PSM" would be part of the Workshop. Also for the independent mode (The Titan IIIC LTEP), the displays and controls shown in the "OWS" block would be nonexistent. Later, for the manned independent mode, they could be added into the MOTEL man-cell. The figure shows all three torquing systems and their appropriate control interconnects. The following is a description of the system function.

a. The telescope will be initially locked in a neutral position by the caging mechnism until the total vehicle is pointing roughly at the target star (for observation) while maintaining a roll reference using a second reference star (Canopus or other).

b. The inner reference for vehicle attitude is provided by three body-mounted, single degree-of-freedom, rate integrating gyros.

c. Signals from the gyros are applied through compensation and deadband circuits to the SIVB RCS thruster valves or to the PSM thruster valves. The same gyro signals are processed to generate the necessary CMG control signals.

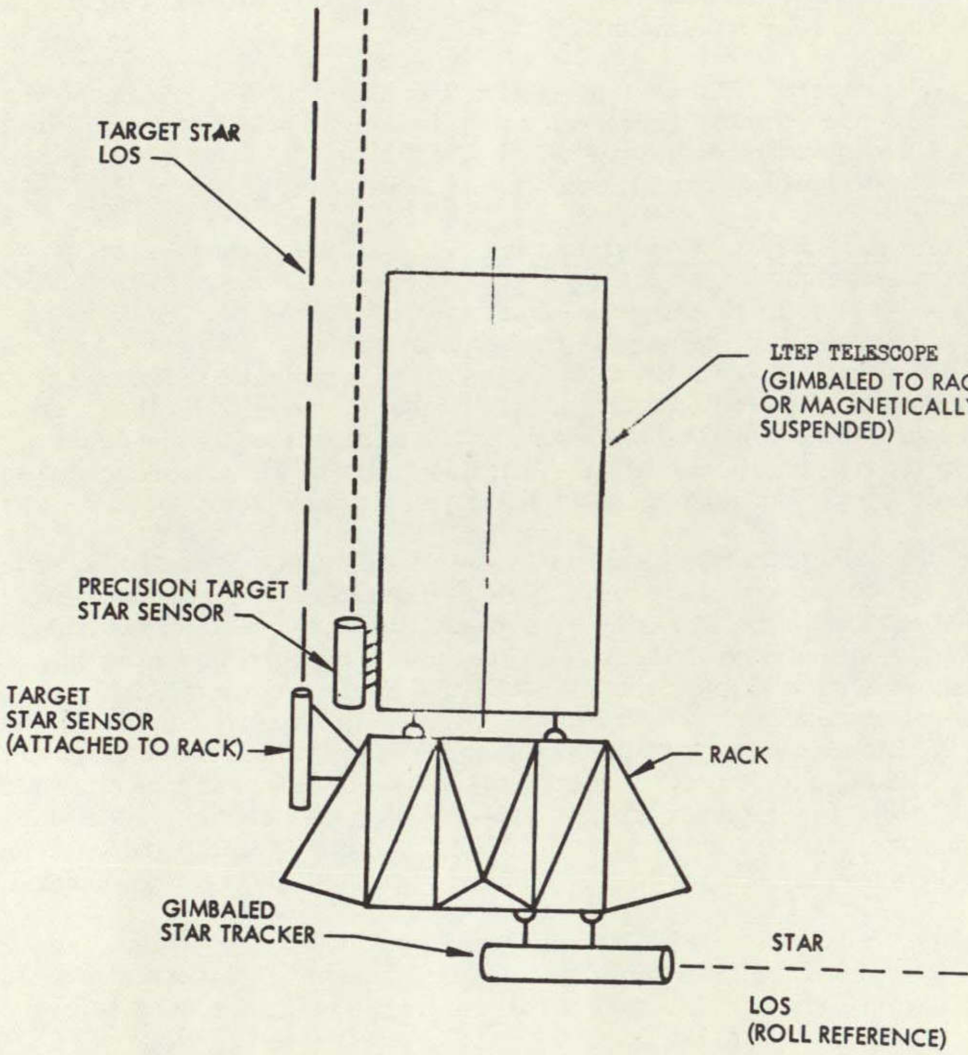


Fig. 48 Stellar Sensors on LTEP Module

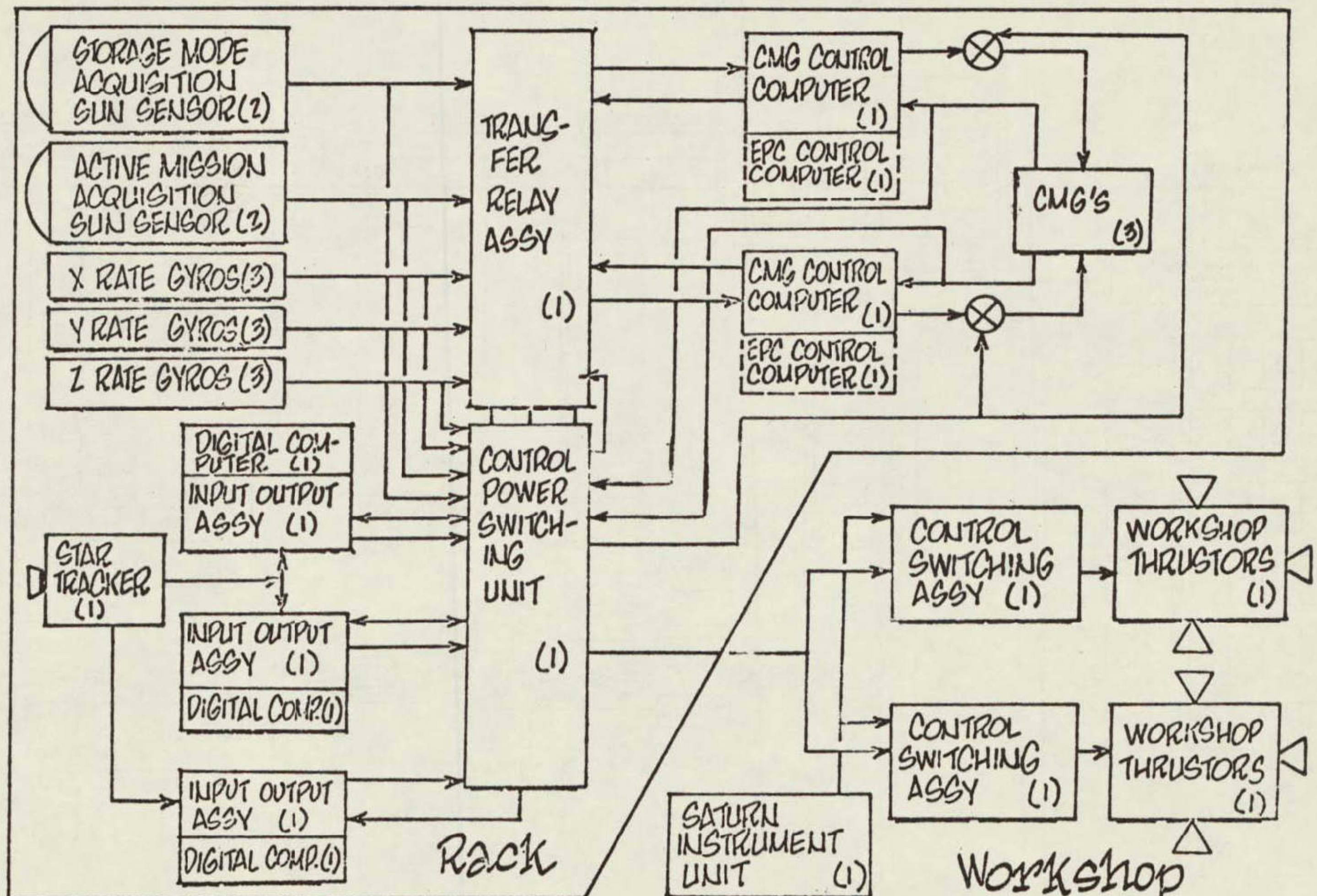


Fig. 49 Basic Block Diagram of ATM Control System (for Dry Workshop)

3

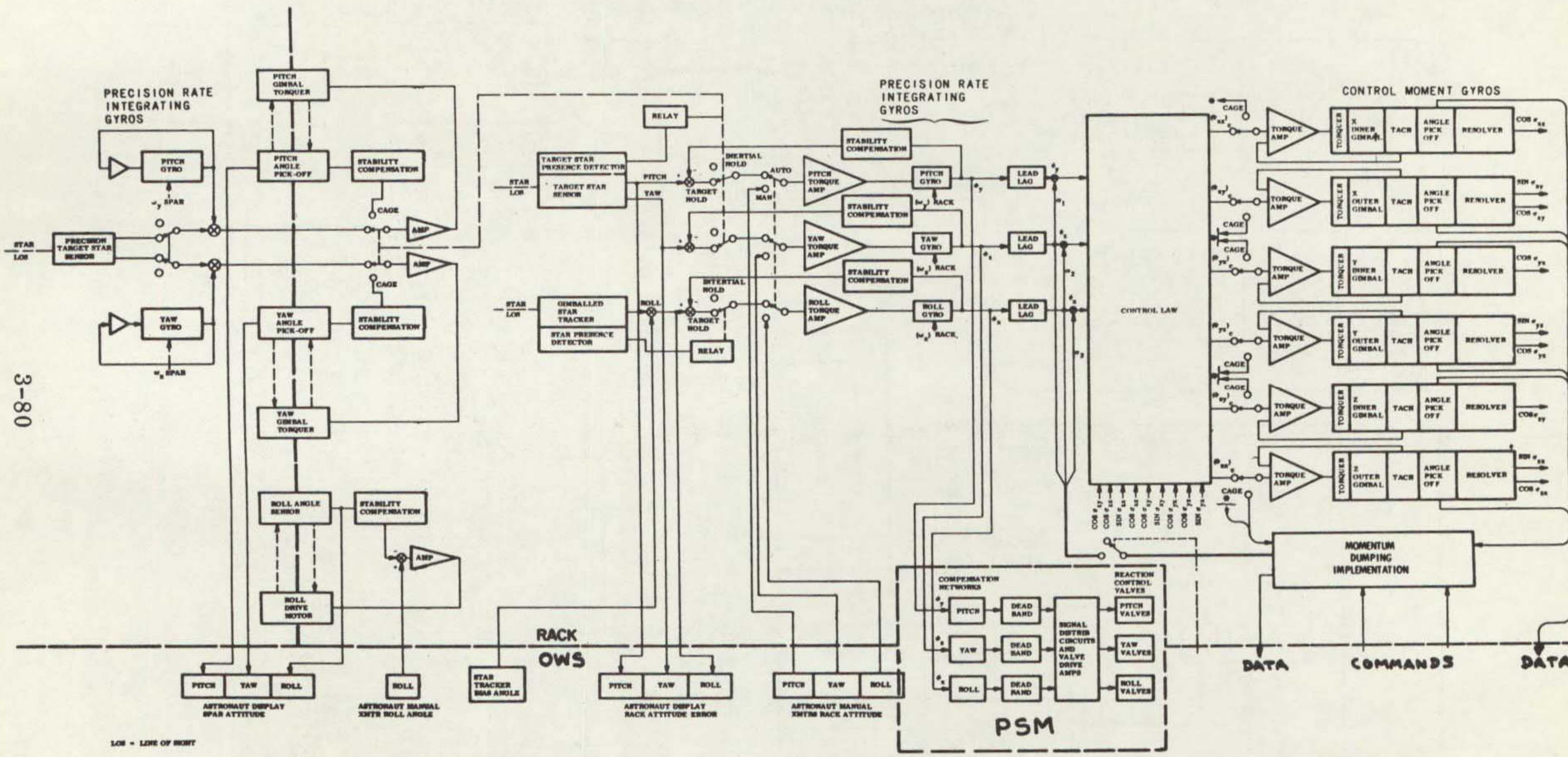


Fig. 50 Control System Schematic for LTEP

d. The CMG's provide a vernier moment generation system within the deadband of the reaction control system. When the CMG's are not capable of compensating for a particular disturbance, and overload condition occurs, the CMG's are driven to their gimbal limits or to an orientation where the spin axes are parallel.

e. When this condition occurs, the RCS is activated. The RCS is in operation also when any other particular error signal indicates vehicle position is outside the RCS deadband.

f. During periods of star occultation, the absence of the signal from the star sensor releases a relay and the attitude reference reverts to the integrating gyros alone. The gyros will hold the vehicle so that the star, when next contacted, is within the field-of-view of the acquisition star sensor for automatic acquisition.

A specific feature of the control system described which must be further investigated, is the "automatic" activation of the RCS thrusters if the CMG's reach limit travel or if the gyros indicate out of "deadband." A delay may be necessary in the system to allow time for closing the telescope sun-shield (to protect the inner optical elements) before the RCS thrusters are fired and potentially create a contaminant flux into the telescope cavity.

The components of the ATM control system have been designed and tested to specifications requiring 270 days operation. In fact, the CMG's were tested to a much shorter life time criteria and reportedly are now undergoing modifications to provide the 270-day operating ability. Because these mechanical (rotating) units are subject to wearout, a thorough evaluation must be made considering their use for the two years required life of the LTEP system. Although the electronics of the control system are probably capable of the longer life, further investigation is required here also. The integrating gyros must also be fully assessed for life capability. It is not feasible to "replace" the total ATM control system nor does it presently appear desirable or practical to replace the large CMG assemblies (420 lb each); at least in the Independent mode and assuming that the CSM is the maintenance/supply vehicle. With the Space Shuttle, however, replacement of larger units becomes readily feasible and, in fact, the total LTEP Module could be overhauled in orbit or brought down for earth-based overhaul and redeployed to orbit via a later Shuttle flight.

3.4.4.4 Future Analysis Effort. The development of spectrums combining amplitudes and frequencies of the LTEP control system of optimization to lower the frequencies will require considerable additional analysis. For follow-on Phase B effort, these basic tasks are proposed:

a. Obtain and analyze the data from recently completed NASA/MSFC simulation runs on the ATM control system.

b. Determine by analysis and/or extrapolation of test data spectrums of amplitude versus frequency versus angular rate output of the CMG/PCS control loops as they are planned for the Dry Workshop Cluster.

c. Superimpose analytically the moments of inertia of the LTEP telescope gimballed mass and determine effects upon ATM control system response.

d. Investigate specifications, design details, and test data on the components of the ATM control system to determine capability for surviving a 2-year or longer operating life. Identify "critical" components for consideration as redundant passive elements or as replacement spares.

e. Develop a detailed functional schematic for the control subsystem in the LTEP Propulsion/Support Module to supplement the ATM control system in the Independent LTEP flight mode. Also, define the specific functional interfaces with the ATM system.

These five elements form a significant portion of the total spacecraft recommendations summarized in Section 6.

3.4.5 Communications and Instrumentation (C&I) Subsystem

The requirements and constraints for the subsystem in the Cluster-attached mode, as influenced by the recent change by NASA to the AAP Dry Workshop, were investigated. The elimination of the LM Ascent Stage from the Cluster and from the LTEP Module requires that equivalent communications/data processing equipment be mounted respectively in the Cluster Airlock Module and in the LTEP Propulsion/Support Module. The subsystem requirements and operating characteristics and a preliminary evaluation of components are summarized in the following paragraphs. Details of the C&I Subsystem requirements analysis are contained in Appendix D.

3.4.5.1 Requirements and Constraints. The mission and orbit limitations are listed, operational modes described, and general system requirements delineated.

a. Mission and Orbit Limitations. The LTEP system will be launched as an experiment attached to the AAP Dry Workshop or flown independently. It will orbit in a nominal 220 nm altitude circular orbit inclined 35 deg through ETR. All subsystem elements must operate a minimum of two years and be capable of operating life extension to 10 years by maintenance or parts replacement (manned operations). The orbiting LTEP System will be inertially stabilized and pointed to a stellar target for continuous periods from several hours to as long as several days. The pointing line-of-sight can be to any point in the universe except it may not intersect a cone generated by a 45 deg half angle about the earth-sun line. The orbit period will be about 90 minutes.

   Table 8 is a tabulation of the available ground stations listing the data-link capability. This network, or portions thereof, will also support the Independent LTEP orbiting system. The total time available to transmit data to a ground station is a variable. The contact time for a particular station usually exceeds 4 minutes and is frequently in excess of 7 minutes. Values for the 220 nm orbit will be similar.

Table 8

MSFN STATION SUMMARY

Site	Identification	Unified S-band				C-band Radar	VHF	UHF	VHF/AM	Single/ Dual (Antenna
		CMD	TLM	TR	Voice	TR	TLM	CMD	Voice	Diameter)*
1 Cape Kennedy	KSC	X	X	X	X	X	X	X	X	D (30 ft)
2 Grand Bahama	GBM	X	X	X	X	X	X	X	X	S (30 ft)
3 Bermuda	BDA	X	X	X	X	X	X	X	X	S (30 ft)
4 Antigua	ANG	X	X	X	X	X	X	X	X	S (30 ft)
5 Grand Canary	CYI	X	X	X	X	X	X	X		S (30 ft)
6 Ascension	ACN	X	X	X	X	X	X		X	D (30 ft)
7 Madrid, Spain	MAD	X	X	X	X					D (85 ft)
8 Pretoria	PRE	(Teletype Only)			X	X	X**			
9 Tananarive	TAN				X	X	X**		X	
10 Carnarvon	CRO	X	X	X	X	X	X	X	X	D (30 ft)
11 Honeysuckle, Creek	HSK	X	X	X	X	X				D (85 ft)
12 Guam	GWM	X	X	X	X		X		X	D (30 ft)
13 USNS Range Tracker	RTK				X	X				
14 Kauai Hawaii	HAW	X	X	X	X	X	X	X	X	D (30 ft)
15 So. Vandenberg	CAL				X	X			X	
16 Goldstone	GDS	X	X	X	X					D (85 ft)
17 Guaymas, Mexico	GYM	X	X	X	X				X	S (30 ft)
18 White Sands	WHS				X	X				
19 Corpus Christi, Texas	TEX	X	X	X	X		X	X	X	S (30 ft)
20 USNS Vanguard	VAN	X	X	X	X	X	X	X	X	D (30 ft)
21 USNS Redstone	RED	X	X	X	X	X	X	X	X	D (30 ft)
22 USNS Mercury	MER	X	X	X	X	X	X	X	X	D (30 ft)
23 USNS Huntsville	HTV		X	X	X	X	X		X	S (12 ft)

*30 ft. = 44 db gain; 85 ft. = 52 db gain

**Record Capability Only

Ref: 1. TRW Note No. 66-FMT-437, Apollo Mission AS-207/208A Spacecraft Reference Trajectory, 19 Sept. 1966
2. "Station Utilization for Apollo Mission AS-207/208A", NASA Memorandum from FC/Chief, Flight Control Division, 21 July 1966
3. "MSFN Capabilities and Implementation for Apollo Missions," NASA Memo from FS/Chief, Flight Support Div., 7 July 1966

b. Bit Rate. The Apollo-type system will have capability of transmitting data to earth at a rate of 51.2 KBPS.

c. Operational Modes. The following LTEP operational modes are applicable and will have an effect on subsystem design:

(1) Cluster - Attached. In launch, ascent and orbit, communications will be via the Cluster communication system. A hardline connection will carry all data from the LTEP Module through the MDA interface to the Cluster.

(2) Cluster - Remote. At some time during the Cluster manned operations or at the end of the Cluster operational period, the LTEP Module will be released from the Cluster. In the freeflight mode, the LTEP system must maintain RF contact with the Cluster and/or with earth, receiving commands and transmitting data. The LTEP Module must also have transponding equipment aboard to allow ground tracking and commanded rendezvous for redocking to the Cluster.

(3) Independent. The LTEP Module will be launched on the Saturn IB or the Titan IIIC and be placed in orbit respectively by the SIVB or the Transtage upper stage. During the ascent and initial orbit periods (prior to release from the upper stage), the LTEP system must provide the minimal payload status transmission to earth. The CSM will rendezvous and dock for limited time periods for inspection and maintenance by astronauts.

The Communications and Data Processing Subsystems will:

- Receive, decode, and distribute all ground commands
- Collect, store, convert, and transmit experiment data and support subsystem status to earth
- Provide transponding for earth tracking or rendezvous with CSM

A hardline connection at the CSM docking port in the Propulsion/Support Module (PSM), which is connected manually by astronaut after CSM docking, will contain safety-monitoring circuits for the LTEP system and certain LTEP subsystem status circuits. Voice communication of astronaut(s) in EVA with CSM will be via umbilical hardline to CSM or via RF from back-pack to CSM. The CSM communications system will be "on" during the docked period and all voice down-link will be transmitted by the CSM.

(4) Independent with MOTEL. The LTEP Module, including an added element, the MOTEL life-cell, will also be launched into orbit by a Saturn IB. The communications/data processing requirements will be the same as described in paragraph (3) except that the hardline to CSM docking interface will include circuitry for monitoring pressure and temperature within the MOTEL and possibly voice intercom wiring from MOTEL to CSM.

3.4.5.2 C&I Subsystem Characteristics. The functional characteristics of the existing Cluster Communications and Instrumentation subsystem and the proposed LTEP subsystem are described herein.

a. Existing AAP Cluster System. To provide insight into the Cluster/LTEP interfaces, the pertinent features of the Cluster Communications and Instrumentation subsystem are provided.

(1) Overall System and Block Diagram. The new AAP Dry Workshop Cluster will provide the functions previously performed by the CSM (the CSM is dormant in the new arrangement). Real-time voice, TV, and ranging capability have been added to the AM of the Cluster. Total functions include:

- Receive and distribute all ground commands
- Monitor selected parameters during launch and orbital operations and communicate information to ground stations
- Provide tracking data to ground stations
- Provide real-time and delayed-time voice communication
- Provide ranging system for rendezvous with CSM
- Provide TV communication to the MSFN (small hand-held TV camera)

The quantity of data channels for the Saturn V Workshop Cluster, including experiments, is as follows:

Airlock Module (AM)		499 parameters
MDA		62
Workshop (OWS)		247
ATM		960
	Total	1,768 parameters

During Cluster storage in orbit, only selected parameters will be monitored; about 20 percent of the quantities noted.

Changes to the previous Saturn I Workshop were:

- Shutdown of CM S-Band and audio center after docking
- Elimination of UHF Command and VHF/FM telemetry
- Simplification in satisfying storage mode and experiment requirements

The new overall system is shown in block diagram form on Fig. 51.

(2) Cluster Communications Characteristics. The Cluster communications system is a duplex S-band system similar to the Unified S-Band (USB). Differences exist only in the premodulation processing, which matches the Cluster up and down-link signal characteristics with the USB transponders and transmitters. The precision ranging is integral with the USB and allows active tracking of the orbiting Cluster.

The Cluster S-band antenna array, similar to the CSM omni antennas will provide a toroidal-shaped pattern whose axis of symmetry is the longitudinal axis of the Cluster. Switching to individual pairs of antenna elements for desired sector coverage is provided by the attitude control system (ACS) computer.

- Pulse Modulation (PM) Down-Link

  AM Delayed-Time T/M } shared
  Ranging }
  OWS T/M
  OWS Voice

- Frequency Modulation (FM) Down-Link

  ATM Delayed-Time T/M } shared
  Delayed-Time Voice }
  TV
  OWS Voice (Backup)
  ATM Real Time T/M

- Pulse-Modulation (PM) Up-Link

  Up-Voice
  Up-Data
  Ranging

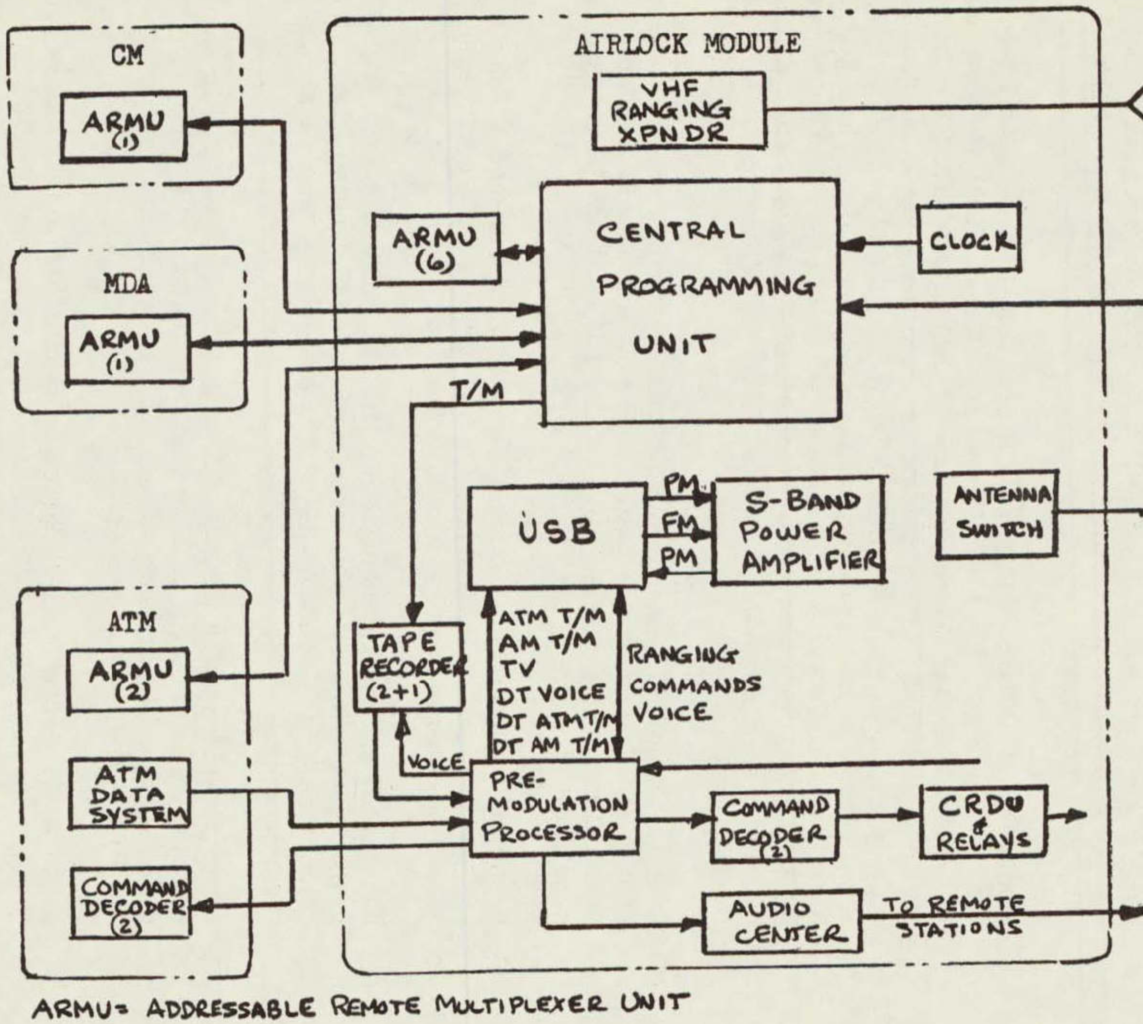


Fig. 51 Saturn V Dry Workshop Instrumentation and Communication System

(3) Cluster Data Processing. The Cluster data system uses multiple format, changeable bit rate, and addressable multiplexing techniques. The Central Programming Unit (CPU) converts available addresses to serial digital form outputs. In addition to the addressing functions, the CPU contains input/output circuitry to process data from remote multiplexers and direct inputs, time-correlating these data to form a continuous serial PCM bit stream. The present format content is 51.2 KBPS with a word length of 8 bits. The tape recorder will record two tracks of data; one will record the AM T/D data or experiment data, the other will record voice. Capability will be 160 minutes recording and 5 minute playback.

Addressable Remote Multiplexer Units (ARMU's) will be located near the data sources. Each ARMU will interface with the CPU on two pairs of cables, one pair for address and clock and one pair for data return. The ARMU's contain their own power supplies. The number and mix of high-level, low-level, bi-level, digital inputs that each ARMU will contain is flexible with up to 120 analog inputs possible. The ATM data system utilizes its own T/M and recorders during experiment operation with transmission through the Cluster AM-S-band system. During storage and non-experiment periods, ARMU's will provide all ATM data to the CPU in the AM.

(4) Cluster Command System. The ground command signals modulate a single 70 KHz subcarrier on the USB PM carrier and are demodulated in the Cluster USB unit. The standard 1 KHz and 2 KHz signals are provided to the AM and ATM decoders.

(5) Cluster TV. Provision is made for only one hand-held TV unit. The analog TV signal will modulate the non-coherent FM carrier in the USB on a time-shared basis with delayed voice.

(6) Cluster Rendezvous Ranging. A VHF/AM ranging system is provided in the Cluster to allow turn-around of the CSM ranging tones. Hardware comprises VHF antenna, VHF/AM transceiver, and a range tone transfer assembly.

(7) LTEP Interfaces with Cluster. Except for a lack of capability to transmit high-resolution (up to 5000 lines per frame), TV data to ground stations, the Cluster system is capable of handling all requirements of the LTEP system.

In the mode where the LTEP Module is attached to the Cluster and hard-line-connected into the MDA, all up-link data receiving and down-link data transmitting will be accomplished by the Cluster system. Detailed command decoding and data conversion for multiplexing for the LTEP telescope and experiment packages will be accomplished by the LTEP system elements and received/transmitted hard-line via the ATM Rack.

Because the LTEP system must be capable of independent operation after separation from the Cluster, the complete LTEP Communications and Instrumentation Subsystem must be installed in the LTEP Module for Cluster-attached operation. Switch-over circuitry will be provided to automatically switch to the Independent mode when the hard-line connection to the Cluster is opened during separation from the Cluster. Redocking to the Cluster and reconnection of the hard-line would reverse the operation and the Cluster would again become the primary data receiving/transmission element of the combined systems.

b. LTEP C&I Subsystem Description. In the Independent flight mode, the LTEP Module will have its own complement of data processing and communications equipment so it can:

- Receive data and commands from earth-base, Cluster or Space Station, CSM, or Space Shuttle, and decode and distribute to internal units.
- Collect, store, convert and transmit data to earth and/or to one of the orbiting vehicles.
- Perform transponder function for tracking by earth station and rendezvous with Cluster or Space Station, CSM, or Space Shuttle.

The following is a discussion of the subsystem characteristics.

(1) Operating Characteristics. The subsystem will have a maximum bit-rate transmission capability of 51.2 Kbps. All up-link data will be received at 21000-2110 MHz. Down-link data will be transmitted PM at 2287.5 MHz. TV only will be transmitted FM at 2277.5 MHz. The existing Manned Space Flight Network (MSFN) ground stations are adequate for the Cluster/LTEP orbiting systems. Ground contact period will vary from four to seven minutes, quite sufficient for LTEP data dumps.

(2) Block Diagram. Figure 52 is a block diagram showing data/command flow in the subsystem matrix.

(3) Equipment List. Subsystem components, with weights, are listed on Table 9. All major items are derivatives of Apollo and other spacecraft programs, with the exception of the TV camera.

(4) TV Transmission. It is assumed that completed pictures of stellar fields or single stars will require transmission to earth. Capability will be provided in the LTEP for the Communication and Instrumentation Subsystem to transmit a high resolution image. The Cluster transmitting system will require a minor modification to allow the same high-bit-rate transmission. It is assumed that the TV camera itself will be part of the experiment package.

Table 9

EQUIPMENT LIST - LTEP COMMUNICATIONS AND INSTRUMENTATION

	Vehicle Qty.	Total Wt. (Lb)	Used on Program Previously
Antenna-Cavity backed spiral	6	6.0	New
Boom-antenna	2	4.0	New
Switch -RF - 8 Port	1	3.5	New
Transponder - Unified S-band	1	33.0	Apollo CM
Telemetry unit - digital-programmable central	1	16.0	LMSC
Multiplexer - addressable remote	1	9.0	LMSC
Premodulation processor	1	14.5	Apollo CM
Up-Data link (command decoder)	1	20.6	Apollo CM
Command logic unit	1	12.0	LMSC
Programmer - stored command	1	10.0	LMSC
Amplifier-triplexer assy., TWT, S-band	1	30.0	Apollo CM
Subsystem interconnect cabling	1 set	15.0	New
(Camera - TV)*	1	(9.0)*	Commercial
TOTAL SUBSYSTEM 173.6 LB			

*Note: TV camera is shown for reference only. Weight assumed to be included in total for experiment packages.

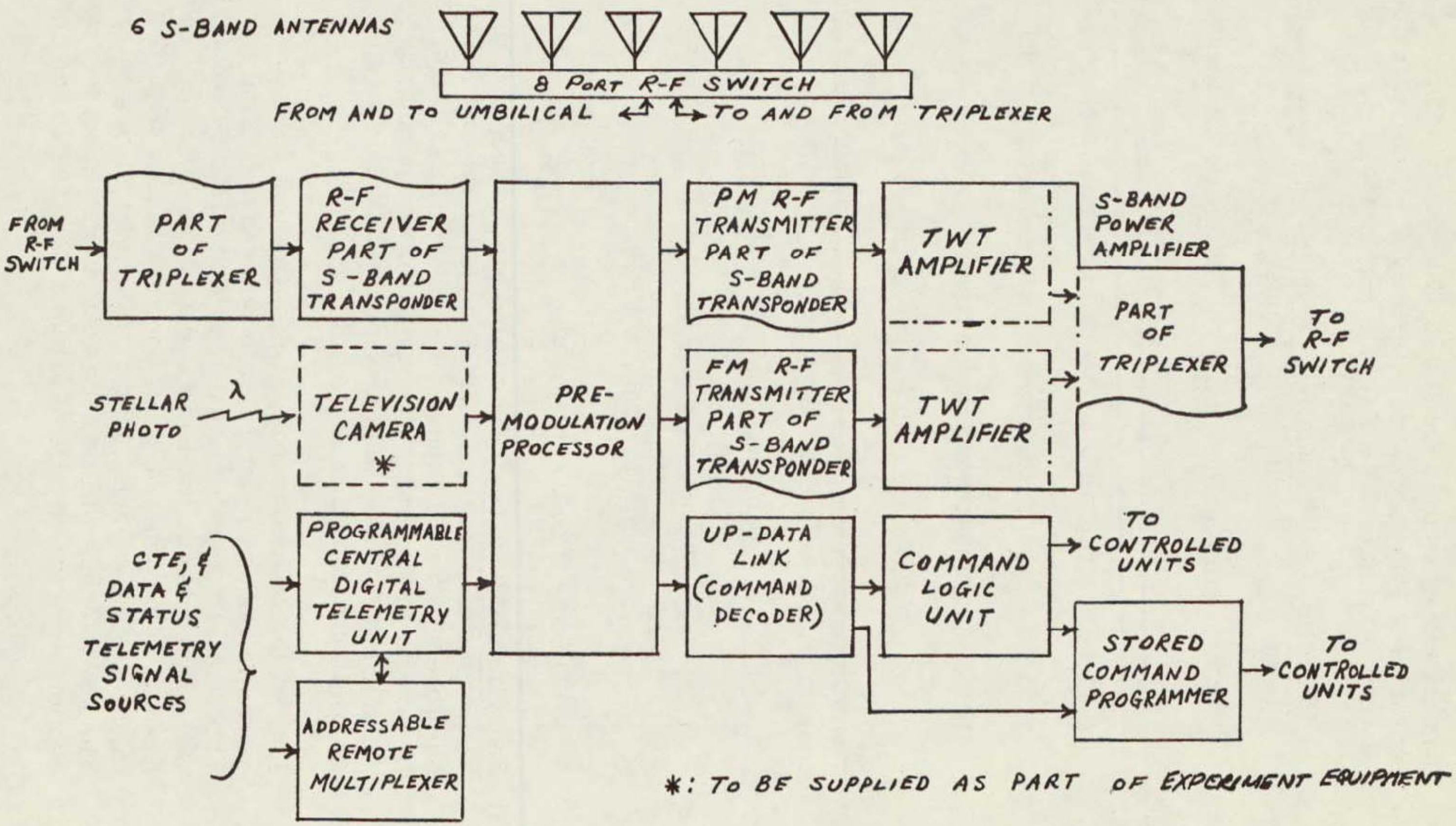


Fig. 52 LTEP Communications & Instrumentation Subsystem Block Diagram

It is estimated that between 50 to 100 lines per mm is adequate to reproduce a 12th magnitude star image. A sample calculation follows for transmitting by TV a 2-1/4 x 2-1/4 photo:

$$\left(\frac{100 \text{ lines}}{\text{mm}}\right) \left(\frac{25.4 \text{ mm}}{\text{Inch}}\right) \left(\frac{2.25 \text{ inch}}{\text{frame}}\right) = 5715 \text{ lines/frame}$$

To attain similar horizontal resolution, at 5000 elements per line,

$$\text{Total elements per frame} = 25 \times 10^6$$

A 14-level grey scale has been chosen requiring 4 bits per element:

$$(25 \times 10^6 \text{ elements/frame})\ (4 \text{ bits/element}) = 10^8 \text{ bits/frame}$$

For a 3-minute transmission time:

$$(10^8 \text{ bits/frame} \div (180 \text{ sec}) = 555,555 \text{ bps}$$

The following typical TV transmission schedule is proposed for a station contact total time of four minutes:

- 30 sec - Acquisition and initial command
- 10 sec - Transmitter warmup
- 180 sec - Transmission
- 20 sec - Closing command

(5) Subsystem Installation. The various components of the C&I subsystem will be installed in the LTEP Propulsion/Support Module (PSM) in temperature-controlled equipment compartments. Figure 53 is an illustration of the PSM showing the equipment compartment locations and the antenna positions. The stowed position of the two boom-antennas is shown in phantom-line on the bottom of the PSM.

Four of the omni antennas, each with a 125 deg solid-angle electromagnetic radiation pattern, will be mounted on the exterior of the PSM. Three will be mounted equally-spaced on the cylindrical shell; the fourth will be mounted on the bottom plate of the module. The other two antennas will be mounted on short booms with axis of pattern parallel to the telescope line-of-sight. They will have a 65 deg solid-angle pattern. The six antennas will provide a 4π solid-angle coverage with selectable section coverage (by use of antenna selector switch command).

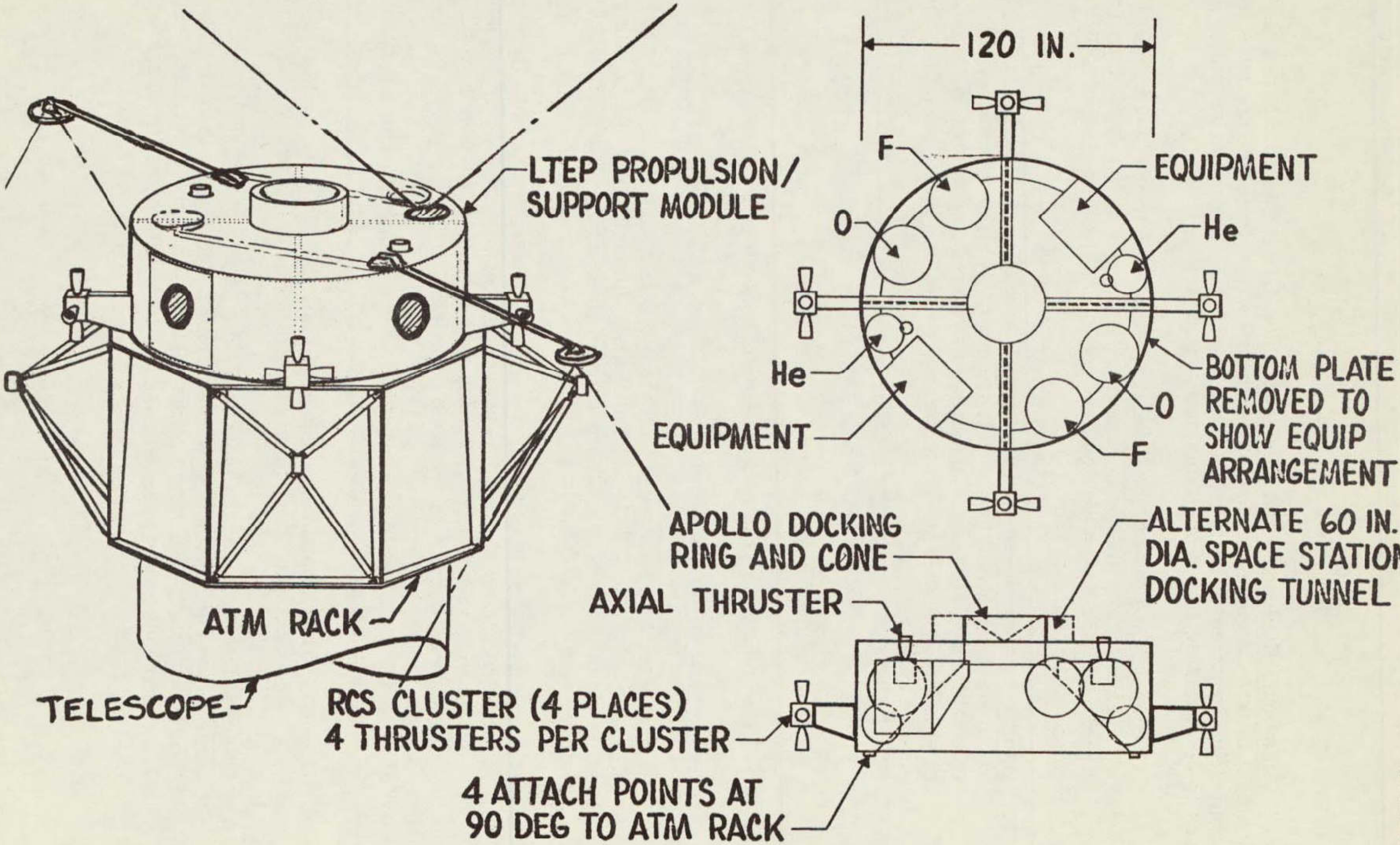


Fig. 53 Propulsion/Support Module and Communications/Instrumentation Installation

3.4.5.3 Component Evaluation and Selection. The LTEP C&I subsystem requires no development of new concepts. A few of the tentatively selected components will require minor modification to adapt them to the LTEP system. The major potential problem appears to be operating life of available componentry.

a. Antennas. Designs for the S-band antennas are in existence. Matching to the LTEP vehicle will be necessary. Each is a cavity-backed spiral type (approximately 3 inch dia. by 1.5 inches deep) with a gain of 3 db relative to an isotropic radiator.

b. Apollo CM Components. Components developed for the Apollo CM have been selected to minimize new development costs. Their relatively short-rated operating life (200 hours) has been considered in conjunction with their relatively good mean-time-between-failure rating (50,000 hours). The units selected are:

   - S-band transponder
   - Premodulation processor
   - Up-link data equipment (command decoder)
   - S-band power amplifier

   Because most of the Apollo C&I hardware is rated at 200 hours of operating life (far below the LTEP requirements), contacts were made with NASA/MSFC to determine actual capability of these components. The following information was obtained:

   (1) Experience at NASA/MSFC previously has been essentially with the Saturn vehicles which are required to operate during short periods in launch, ascent, and orbit. Longer operating life will have to be considered for the AAP Cluster missions.

   (2) No life test has been performed on the short-life-rated Saturn articles. Reliability predictions are used.

   (3) AAP Workshop time schedules do not provide time for new development; hence, existing units must be modified to attain added life requirement.

c. Other Space Qualified Components. The remainder of the existing components were selected on the basis of relatively longer life rating (18 months "operating life", including ground-testing; 6 months orbital life rating; 720 continuous hours rated) and actual long-life operating experience in military programs. The programmer has a rated 9 months orbital life. These components are:

- Programmable Central Digital T/M Unit
- Addressable Remote Multiplexer
- Command Logic Unit
- Stored Command Programmer

d. Special High Resolution Camera TV. In Volume I of this study, TV cameras suitable for the astronomy mission were studied by Perkin-Elmer. At the present time, there is more than one candidate camera which may be useful in the telescope design. The data transmission requirements of the most likely candidate camera will be determined during the phase B follow on program.

e. Alternative Long-Life Approaches. Many of the hardware elements are probably capable of longer operating periods than their current specifications require, but there is presently no validation of this capability by analysis, testing, nor operating experience. Considering the potentially large benefits of using proven hardware (even with shorter operating life), it appears mandatory that a high-priority effort should be implemented to investigate in detail the long-life expectancy of available hardware compatible otherwise with LTEP requirements. One of the following approaches can probably be used:

(1) Verify by analysis and extrapolation of existing test and operation data that components will probably operate for a 2-year period.

(2) Conduct further testing to validate longer life capability.

(3) Make internal changes in components (local redundancy, etc.) to increase operating life; functional retest to prove no alteration to functional characteristics and perform additional life test.

(4) With new life data, establish required stand-by redundancy in subsystem for critical life components. Automatic shift-over from the failed item to the "replacement" would be provided in the circuitry.

Further consideration of the LTEP Communications and Instrumentation Subsystem requirements are provided in Appendix D.

3.4.6 Crew Support Equipment

The LTEP Module will be equipped with various accessories to aid the astronaut in inspection, adjustment, and maintenance/replacement activities in EVA from the Cluster/Space Station or from the CSM or Space Shuttle support vehicles. This section describes the location of hardware potentially requiring access, the access capability provided, and the special features of the astronaut aids. The separate man-cell, the MOTEL, is described in Section 4.4.2.

3.4.6.1 Placement of External Hardware. The following items are accessible to the astronaut directly without opening of any compartment doors:

- Solar arrays and rotation mechanism
- ATM rack equipment mounted on exterior panels
- Screw-jack erection mechanism
- Exterior surface thermal coating on telescope
- Attitude control thrusters
- CMG's (partial)

3.4.6.2 Placement of Internal Hardware and Access. The packages mounted internally and requiring access through openings are shown in Fig. 54. These items are listed on the following paragraphs with the available means of access.

a. Sun Shield and Actuator. If the sun shield is failed closed, an externally-accessible mechanical release will allow actuator decoupling and the shield will open by spring action. Replacement of the actuator may be accomplished from the open end of the telescope tube.

b. Figure Sensor. Access to the figure sensor will be available from the open telescope aperture. No entry of the astronaut is planned past the level of the sensor support webs. Any removal or adjustment of hardware, therefore, must be possible from the outboard end of the sensor.

c. Secondary Mirror. The secondary mirror will be accessible through a single access opening in the intermediate telescope tube section. The door will be hinged on one side and be easily opened outward and closed by an astronaut. A support platform will be mounted in the door-frame opening hinge attached at the bottom. This platform will be folded inward by the astronaut and provide a support for access to the central area of the tube. Figure 55 illustrates the principle.

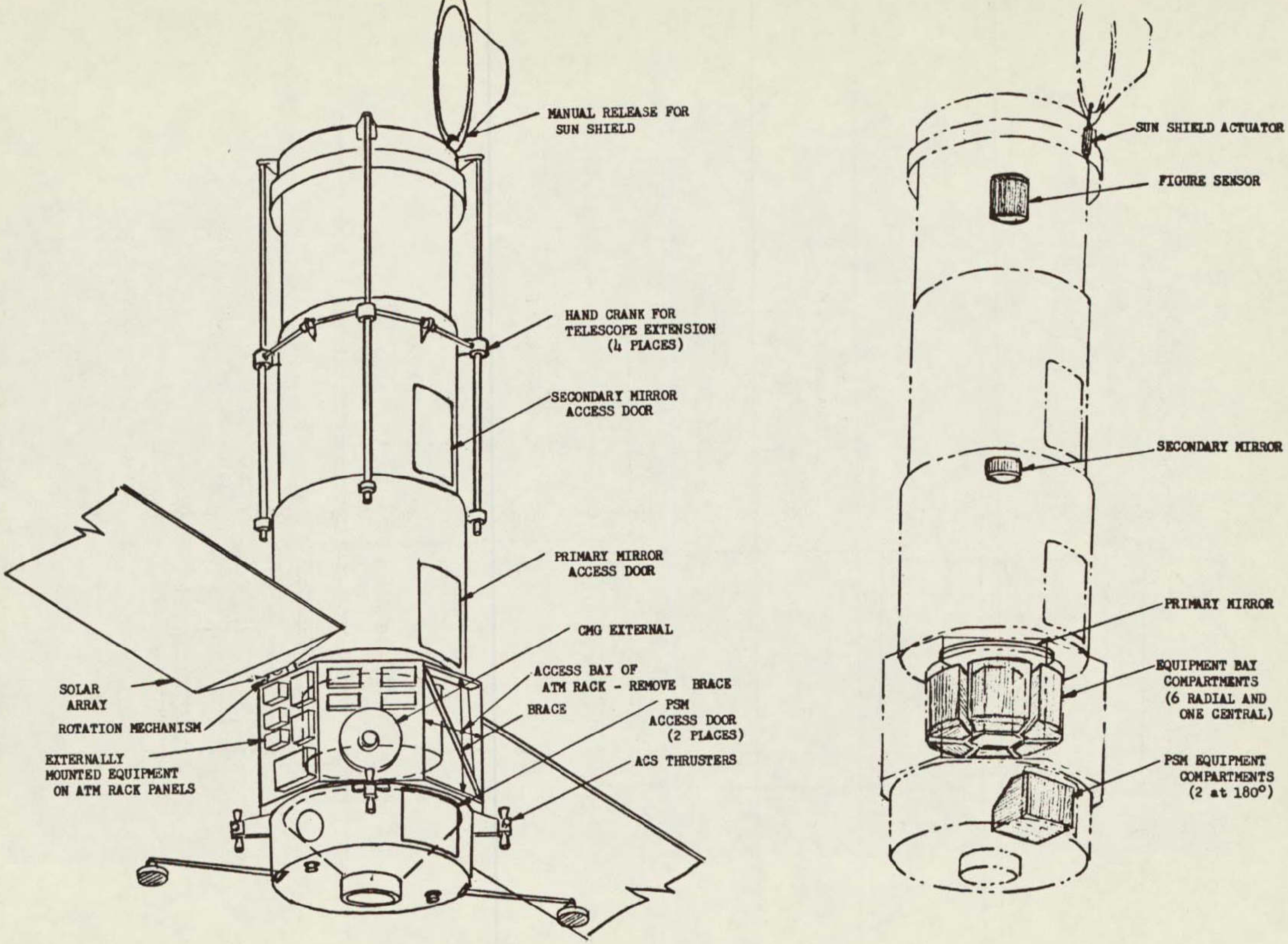


Fig. 54 Placement of Equipment in LTEP Module

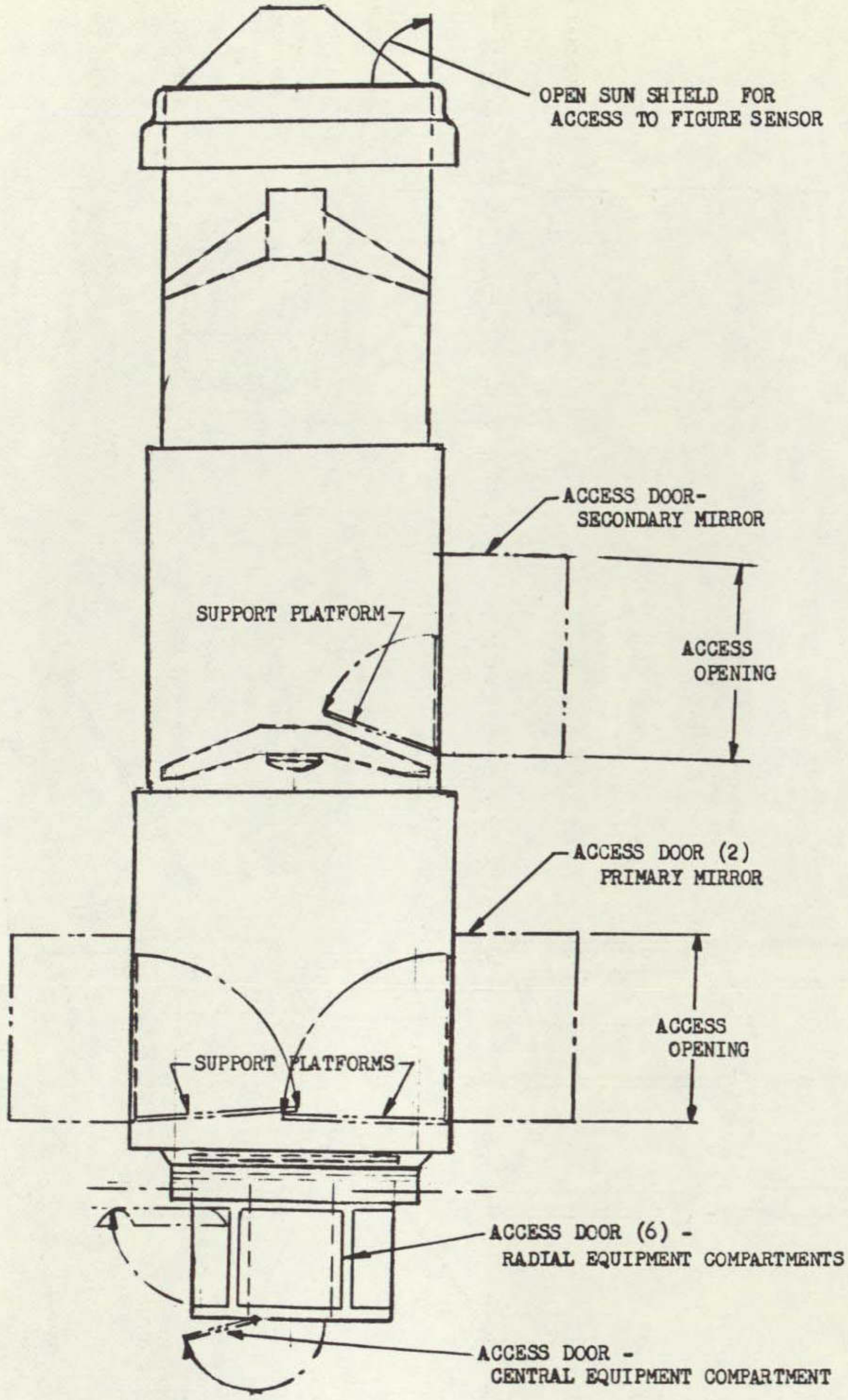


Fig. 55 Access Provisions for Telescope Equipment

d. Primary Mirror. Two access openings will be provided in the fixed section of the telescope tube for access to the primary mirror cavity. The access door and support platform principle will be the same as for the secondary mirror. The general concept is illustrated in Fig. 55.

e. Equipment Bay. The equipment is packaged in seven compartments; a central compartment with six separate compartments arranged peripherally about the central. Each of the six radial compartments will be provided with a quick-opening access door. However, access to the equipment bay exterior in general will be available only through a single opening in the ATM Rack. (The other seven (7) flat areas of the Rack octagon structure are covered by permanent equipment panels.) The cross-brace on this open panel is to be detached and swung to a stowed position. Because the small space between the telescope equipment bay and the inner ATM Rack structure will not allow an astronaut to move around the equipment bay inside the Rack, the roll motors on the telescope gimbal ring must be activated (by remote override switch on Rack at the frame opening) and telescope rotated until the desired equipment bay compartment is aligned with the Rack opening.

The central compartment will be accessible from below. Initial astronaut access will be accomplished through the aforementioned Rack opening, or from below through the docking tunnel of the Propulsion/Support Module (PSM).

f. Propulsion/Support Module. The principal equipment of the PSM is packaged in two diametrically opposite equipment compartments. The interior equipment will be accessible through quick-opening access doors in the outer shell. Equipment will be tray-mounted for partial slide-out to allow inspection, checkout, or replacement of modularized packages.

3.4.6.3 Astronaut Aids. The astronaut(s) will be provided the necessary handholds, foot stirrups, tether attach rings, and tether slide-rails to aid in performing the following functions:

1. Emergency extension of telescope using hand-cranking of extension gear box.
2. Inspection, adjustment, or replacement of figure sensor on secondary mirror package.
3. Inspection, cleaning, or removal/reinstallation of primary mirror segments.
4. Inspection and adjustment of basic structural alignment of telescope optical elements.
5. Replacement of sun shield actuator.
6. Data package retrieval and replenishment.
7. Experiment servicing (filter changes, adjustments, etc.).

3.5 CONFIGURATION SUMMARY

Summary data on The SWS-II LTEP (Mode 1) is presented in this section. The overall evelope dimensions, mass properties data, and basic design parameters are included.

3.5.1 Basic Dimensions

Figure 56 provides the envelope dimensions of the 3-section telescope, the ATM Rack, and the Propulsion/Support Module (PSM). The launch-stowed and the extended telescope positions are separately illustrated.

3.5.2 Mass Properties Data

The axes orientations relevant to the LTEP Module are given in Fig. 57 . Table 10 is a tabulation of summary data from a computer run performed on the LTEP Module. The weights of each telescope element is given with its location relevant to the aforementioned axes. The moments of inertia about the three axes are also listed.

Tables 11 and 12 are similar data for the ATM Rack and the Propulsion/Support Module, respectively. Table 13 summarizes the mass characteristics of the free-flight LTEP Module. The moments of inertia about all three axes are approximately equal.

3.5.3 Design Parameters (Operating Features)

A summary listing of the principal operating features of the LTEP Module is given in Table 14 . The movement limits and pointing accuracy and stability of the structural platform (excluding the optical – extra-fine – pointing system) are provided in Table 15. The basic characteristics of the optical system are illustrated in Fig. 58. The operating temperatures of the telescope assembly and the optical elements are provided in Fig. 59.

3.5.4 Reliability and Quality Assurance Considerations

The LTEP reliability goal for a two-year mission previously has been established as 0.90. Although no additional specific analysis has been accomplished during this study, it appears possible that this coefficient may be achieved, but perhaps for a lesser period of time. Even with use of functional redundancies and standby spares in the various subsystems, a certain few of the components are potentially critical in wear-out life and would be difficult to duplicate in the installation as standby spares; the principal example of this is the Control Moment Gyros (CMG) whose operating continuous-run life initially was rated at 10,000 hours. Section 3.5.4.1 elaborates on the lifetime characteristics of primary components and subsystems. Sections 3.5.4.2 and 3.5.4.3 deal respectively with special reliability characteristics of the design and proposed quality assurance objectives for fabrication and testing phases of the hardware program.

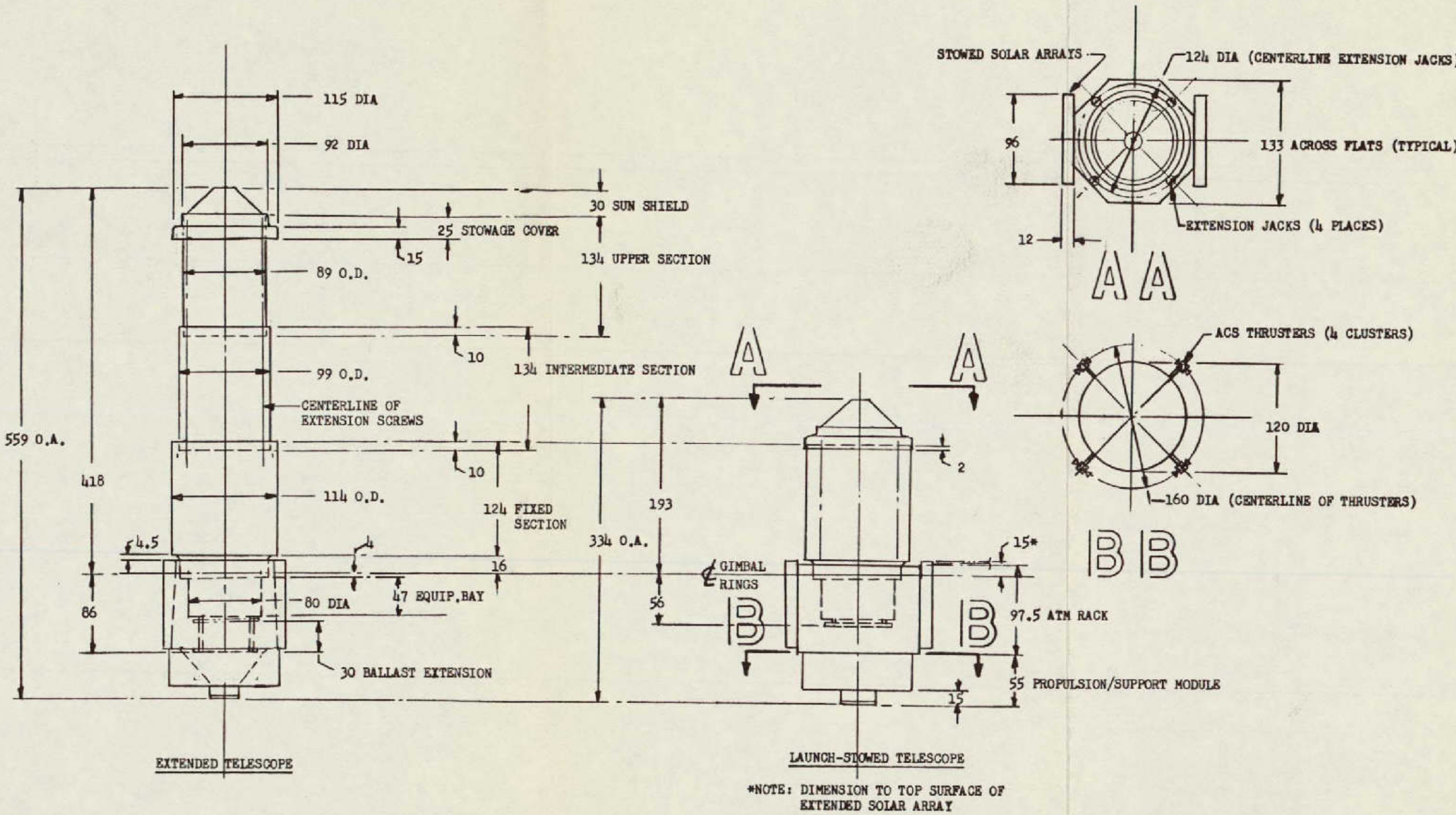


Fig. 56 Basic Envelope Dimensions for LTEP Module

FOLDOUT FRAME 1

FOLDOUT FRAME 2

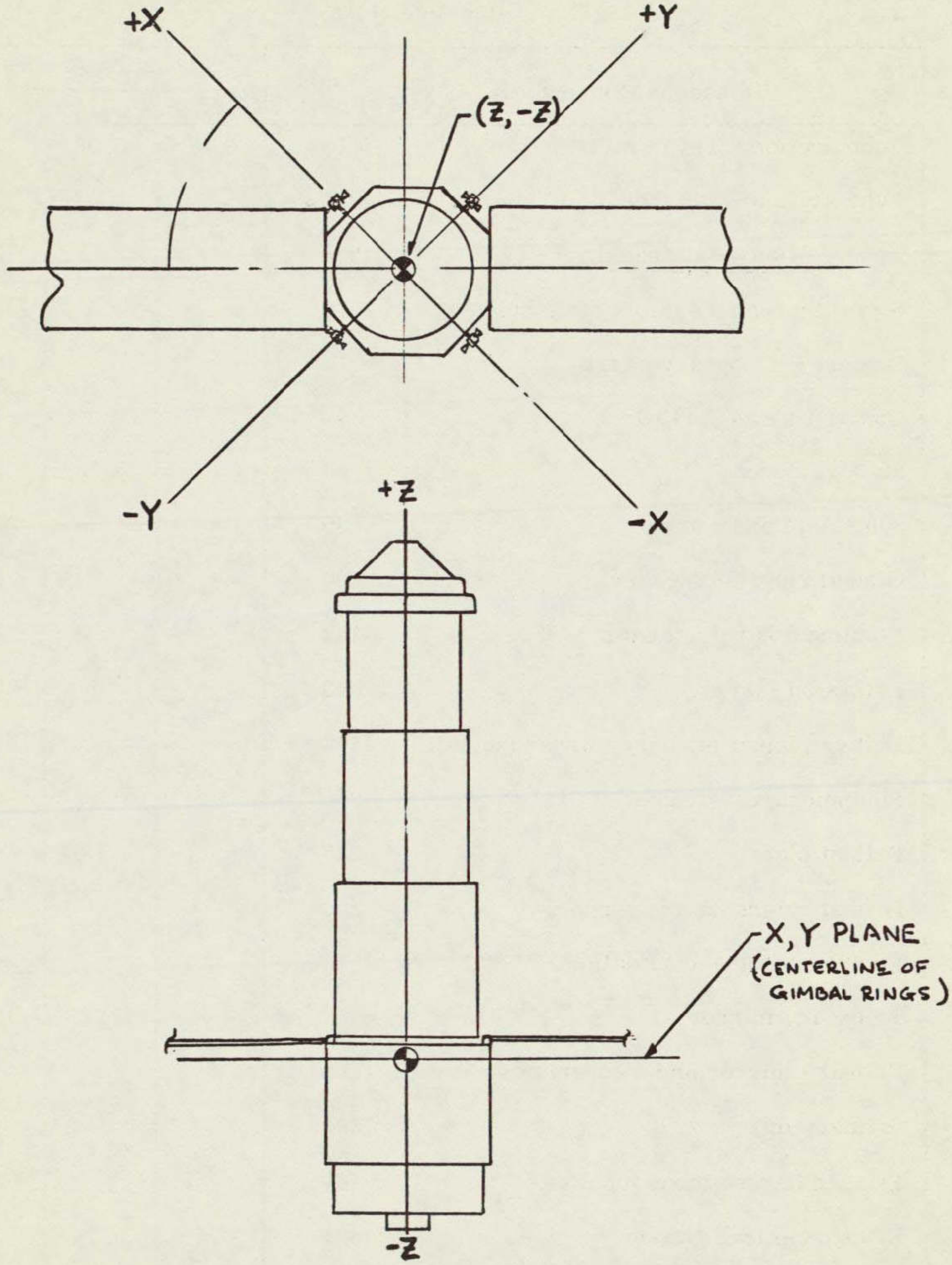


Fig. 57 Reference Axes for Mass Properties

Table 10

MASS PROPERTIES OF TELESCOPE ASSEMBLY
(Gimballed Mass)

Telescope Element	Weight (lb)	Location (Inches)		
		X	Y	Z
Tube section – 114 inch dia.	415	0.00	0.00	78.00
Tube section – 99 inch dia.	375			197.00
Tube section – 89 inch dia.	330			321.00
Support – figure sensor (incl. rollers)	20			330.00
Support – secondary mirror	10			155.00
Quartz rods (4), 140-inch	40			75.00
Stowage cover	20			375.00
Sun shield and actuator	30			388.00
Gimbal ring, 80 inch dia.	190			0.00
Pointing control actuator	132			0.00
Extension system	100			250.00
Bottom plate – primary mirror support	503			7.00
Equipment bay structure	200			-25.00
Ballast plate	385			-85.00
Ballast extension and support	100			-75.00
Figure sensor and actuation	75			343.00
Secondary mirror	50			152.00
Primary mirror and mechanisms	800			10.00
Primary mirror cell	500			10.00
Film and experiment supplies	200			-35.00
Electro-optical system	821	0.00	0.00	-35.00
Telescope Assembly	8096	0.00	0.00	-0.22
Moments of Inertia (Slug-Ft^2)				

$I_x = 23,278$	$I_y = 23,278$	$I_z = 1,388$

Table 11

MASS PROPERTIES OF ATM RACK
(Modified for LTEP)

Rack Element	Weight (lb)	Location (Inches)		
		X	Y	Z
Basic structure	2140	1.50	1.80	-31.50
Equipment mounts	268	4.10	13.30	-39.60
Misc. equip.	37	20.30	0.00	-63.40
Misc. equip.	30	0.00	0.00	-74.20
Misc. equip.	16	0.00	0.00	-78.00
Misc. equip.	64	-39.20	47.80	-19.10
Misc. equip.	20	0.80	1.90	-25.10
CDF/EBW	28	27.60	-26.60	-87.50
Measuring equip.	153	21.30	28.90	-20.10
RF system	74	53.50	-39.60	-18.00
T/M system	377	-4.10	-9.70	-18.80
S/A rotating mech.	100	-50.00	50.00	14.00
S/A rotating mech.	100	50.00	-50.00	14.00
Pointing control system	1891	-1.60	-9.20	-58.70
CBRS – elect.	857	0.00	-23.10	-11.50
Cont. distr. – elect.	51	15.50	24.20	-33.10
Meas. distr. – elect.	51	6.30	-12.60	-70.60
Switch select – elect.	40	-4.00	-19.00	-67.90
Aux. power dist. – elect.	50	41.90	63.00	-60.00
Main power dist. – elect.	35	41.90	63.00	-74.00
Power trans. dist. – elect.	100	60.00	-45.20	-67.70
Transfer assy – elect.	50	37.00	51.00	-66.80
J-box assy's – elect.	24	-27.80	-50.10	-12.60
Cables – cag. gimb. – elect.	50	0.00	0.00	0.00
C&D logic Dt – elect.	50	50.90	37.30	-17.20
Cables – rack – elect.	275	3.60	-1.30	-41.10
Wiring ASAP – elect.	5	-35.00	-49.00	-35.10
Gimbal system	923	-3.40	2.30	-1.60
Thermal control	201	-15.60	27.70	-35.60
Exper. support equip.	90	-45.40	28.80	-77.80
ATM Rack	8150	1.31	-2.91	-33.17
Moment of Inertia (Slug-Ft^2)				

I_x = 5,684	I_y = 5,948	I_z = 7,668

Table 12

MASS PROPERTIES OF PROPULSION/SUPPORT MODULE

PSM Element	Weight (lb)	Location (Inches)		
		X	Y	Z
Struct. + mech.	580	0.00	0.00	-110.00
F/O tank	30	-15.00	45.00	-110.00
F/O tank	30	15.00	-45.00	-110.00
F/O tank	30	-45.00	15.00	-110.00
F/O tank	30	45.00	-15.00	-110.00
He tank	35	-35.00	35.00	-110.00
He tank	35	35.00	-35.00	-110.00
He tank	35	20.00	-20.00	-110.00
He tank	35	-20.00	20.00	-110.00
Axial thruster	15	-32.00	-10.00	-135.00
Axial thruster	15	32.00	10.00	-135.00
RCS cluster assy	20.5	-63.00	0.00	-120.00
RCS cluster assy	20.5	63.00	0.00	-120.00
RCS cluster assy	20.5	0.00	63.00	-120.00
RCS cluster assy	20.5	0.00	-63.00	-120.00
Plumbing/fittings	20	0.00	0.00	-130.00
Valves	43	0.00	0.00	-130.00
Cluster mountg. hdwr	6.2	-53.00	0.00	-117.00
Cluster mountg. hdwr	6.2	53.00	0.00	-117.00
Cluster mountg. hdwr	6.2	0.00	53.00	-117.00
Cluster mountg hdwr	6.2	0.00	-53.00	-117.00
Guid/nav/control	376	0.00	0.00	-115.00
Communications	123	0.00	0.00	-100.00
Instrumentation	50	0.00	0.00	-90.00
Electrical	176	0.00	0.00	-110.00
RCS F/O useable	525	-15.00	45.00	-110.00
RCS F/O useable	525	15.00	-45.00	-110.00
RCS F/O useable	525	-45.00	15.00	-110.00
RCS F/O useable	525	45.00	-15.00	-110.00
RCS F/O residual	22.5	-15.00	45.00	-110.00
RCS F/O residual	22.5	15.00	-45.00	-110.00
RCS F/O residual	22.5	-45.00	15.00	-110.00
RCS F/O residual	22.5	45.00	-15.00	-110.00
RCS He	10	0.00	0.00	-110.00
PSM Assembly	3965	0.00	0.00	-110.67
Moments of Inertia (Slug-Ft^2)				

I_x = 1,190	I_y = 1,196	I_z = 1,961

Table 13

MASS PROPERTIES OF TOTAL LTEP MODULE

System Element	Weight (lb)	Location (Inches)		
		X	Y	Z
Telescope assembly	8,096	0.00	0.00	-0.22
ATM rack	8,150	1.31	-2.91	-33.17
Propulsion/support module	3,965	0.00	0.00	-110.67
Solar arrays	2,035	0.00	0.00	22.70
LTEP Module	22,246	0.50	-1.10	-30.76
Moments of Inertia (Slug-Ft^2)				
I_x = 66,115	I_y = 66,378		I_z = 66,290	

Table 14

LTEP SYSTEM – PRINCIPAL OPERATING FEATURES

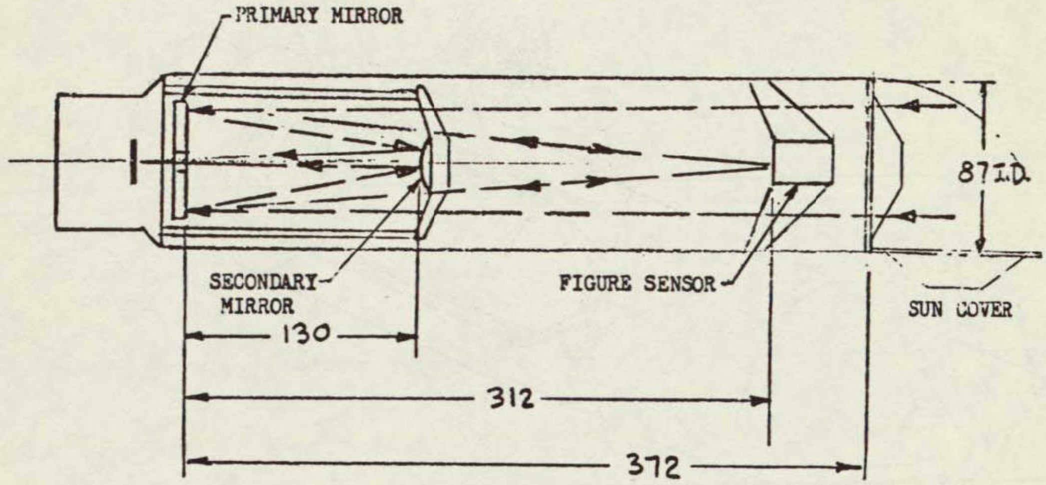
- Accommodation of a full 2-m-diameter primary mirror; either segmented or monolithic
- Employment of a movable secondary mirror and figure sensor
- Accommodation of the experiment for comparison of mechanical and magnetic suspension systems
- Provision for controllable positioning of the telescope center-of-gravity
- Provision for quartz spacer rods to assist in maintaining focus
- Maintenance of low thermal gradients across the diameter of the primary mirror
- Provision for launch "piggy-back" on the AAP Dry Workshop Cluster; same vehicle also may be launched on Saturn IB or Titan IIIC
- Provision for fully-automated erection of the telescope
- Operational flexibility for both Cluster-attached and Independent modes
- Provision for development economy through maximum use of previously developed and qualified Apollo program hardware
- Astronaut participation in maintenance and operational tasks

Table 15

MOVEMENT LIMITS AND POINTING/STABILITY ACCURACY

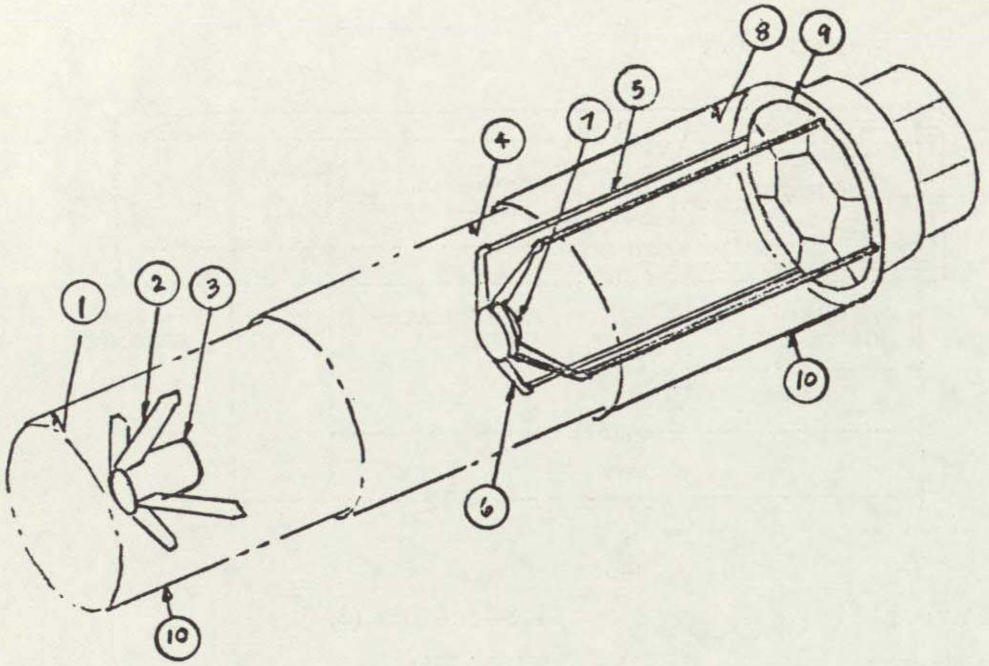
• Telescope Mechanical Limits	
Movement about X and Y axes	±2 deg
Caging position (X and Y)	±10 arc sec
Movement around Z axis (roll)	±95 deg
Roll error (from selected position)	±10 arc min
• Attitude Control Thruster Maneuver	
Coarse Pointing Tolerance – Cluster-Attached Mode	±0.3 deg
Angular Rate (Maximum – Any Axis	0.3 deg/sec
Coarse Pointing Tolerance – LTEP Independent	±1.0 deg
Angular Rate (Maximum) – Any Axis	1.0 deg
• ATM CMG Control Limits* (Without TFPC)	
About X Axis	±215 arc sec
About Y Axis	±345 arc sec
About Z Axis (Roll)	±300 arc sec
• Telescope Fine Pointing Control (TFPC)	
About X Axis	±2.5 arc sec
About Y Axis	±2.5 arc sec
About Z Axis**	–

*2 Sigma estimated values for 15-minute stability period
**EPC subsystem has no closed-loop for roll control; CMGs provide control



Primary Mirror	78.8 inch Dia.(2M)
Secondary Mirror	16 inch Dia.
Figure Sensor	At Center of Radius of Curvature of Primary Mirror
Sun-Shade (Cover)	Closes when Sun-Line is Within 45^{o} of L.O.S.
Field of View	30 Arc Min. (Dia.)
Pointing Star Capability	12th and Lower Magnitude Stars
Wavelength	From Vacuum UV through Visible Light

Fig. 58 Optical Characteristics of LTEP Telescope



1	INNER SURFACE TELESCOPE TUBE-OPEN END NEAR FIGURE SENSOR	-202°F
2	FIGURE SENSOR SUPPORTS	-172°F
3	FIGURE SENSOR	-176°F
4	INNER SURFACE TELESCOPE TUBE-NEAR SECONDARY MIRROR	-125°F
5	QUARTZ RODS-SUPPORTING SECONDARY MIRROR	-101°F
6	SECONDARY MIRROR SUPPORTS	-122°F
7	SECONDARY MIRROR	-123°F
8	INNER SURFACE TELESCOPE TUBE NEAR PRIMARY MIRROR	-100°F
9	PRIMARY MIRROR	- 81°F
10	EXTERNAL TELESCOPE TUBE	-109°F to -124°F

Fig. 59 Approximate LTEP Telescope Operating Temperatures – Power On

3.5.4 Reliability and Quality Assurance Considerations

The LTEP reliability goal for a two-year mission previously has been established as 0.90. Although no additional specific analysis has been accomplished during this study, it appears possible that this coefficient may be achieved, but perhaps for a lesser period of time. Even with use of functional redundancies and standby spares in the various subsystems, a certain few of the components are potentially critical in wear-out life and would be difficult to duplicate in the installation as standby spares; the principal example of this is the Control Moment Gyros (CMG) whose operating continuous-run life initially was rated at 10,000 hours. Section 3.5.4.1 elaborates on the lifetime characteristics of primary components and subsystems. Sections 3.5.4.2 and 3.5.4.3 deal respectively with special reliability characteristics of the design and proposed quality assurance objectives for fabrication and testing phases of the hardware program.

3.5.4.1 Life Requirements Evaluation. There are several components which, in their current hardware configuration, are not capable of continuous operation for two years without maintenance or replacement. Redundant installations of certain of these is feasible. Using the extras as switchover standby spares will increase this overall system operating life. A limited number of components will probably operate for the longer 10-year period, but replacement of total subsystems or portions thereof will be necessary in most cases to extend the operating life of the total LTEP system. The principal characteristics are listed in the following:

a. Optical System. No detail data are available on the electro-mechanical and optical elements; therefore, no analysis has been made of the capability of these elements to survive the basic two-year period nor the longer 10-year period. A basic plan for experiment package replenishment or exchange, along with exchange of optical elements, must be worked out in the follow-on study phase. It appears that the present compartmentization of the telescope equipment bay and segmenting of the primary mirror will allow a reasonable program of replenishment/replacement by astronauts working from the CSM or the Space Shuttle.

b. CMGs. The CMGs are currently rated for 10,000 hours operating life. This will probably be adequate for the 270-day Cluster-attached mission but leaves no margin for longer operation up to two years. Also, the replacement of CMGs is a major task; however, if a set of three could be transported to orbit initially as spares on the Cluster, it is possible that astronauts in EVA could, remove the initial CMGs from the ATM Rack and install replacements prior to the LTEP Module being released for free-flight. The EVA astronaut function is discussed in more detail in Section 5.3.

   Because any two of the three CMGs will sustain stabilized flight, replacement of one unit at a time should be accomplished with the other two continuing to operate. Certain detail modifications may be necessary to allow easy removal/reinstallation of the CMGs and switching one at a time out of the operating loop.

If the CMG replacement can be done while the LTEP Module is attached to the Cluster, it may also be presumed that a replacement by astronauts in EVA from a CSM, rendezvousing with the Independent orbiting LTEP Module, is feasible. However, carrying three CMGs to orbit on a CSM, though perhaps feasible, is considered a difficult task.

c. Electronics. The electronic components of the Control and Communications Instrumentation (C&I) Subsystems probably can be designed with adequate redundancy and standby spares installations to provide two-year capability. Periodic replacement on a planned basis of modular packages for longer operating periods is also considered feasible. Additional analysis and testing must be accomplished on current space-qualified componentry to establish reasonable confidence in a 10-year maintenance/replacement program.

d. Propulsion. The propellant provided in the Propulsion/Support Module tankage will require replenishment after two years. Also, the pressurizing helium tanks will require recharging or replacement. All components of the propulsion subsystem are probably capable of two-year operation; however, the rated total firing time of the attitude control thrusters should be checked against the typical duty-cycle profile for the LTEP Module at such time as the thruster sizes are specifically selected and the mission control impulse requirements are firmed up.

For operating periods longer than two years, it probably will be necessary to replace many, if not all, of the propulsion components except the helium tanks and the plumbing lines. It is not considered desirable nor feasible to separately replace the various bi-propellant components in orbit. Rather, the total propulsion subsystem package should be replaced so that pre-connection and checkout can be done as a ground-based operation. Because the total volume required by the propulsion subsystem is comparatively large, comprising a large percentage of the Propulsion/Support Module, it is proposed that the total Module be replaced at a to-be-specified time with a completely fitted and fuelled new Module. The replacement Module would also include new components of the other subsystems. A CSM could transport the replacement Module to a docking rendezvous with the dormant, but platform-stabilized, ATM/Rack/Telescope (following remote-controlled jettison of the initial PSM from the ATM Rack).

e. Electrical Subsystem. As discussed in Section 3.4.3, the existing ATM solar arrays are probably capable of operating for the full 10-year period. The ATM batteries are quite capable of operating two to three years and could be installed in standby spares mode to be switched on when the initial set reached a predetermined deterioration. To carry a third set, and possibly a fourth, to complete the 10-year operating period might burden the initially-launched LTEP Module (each set of battery modules weighs about 700 lb). It is feasible to replace single modules, about 80 lb each, if the installation provides quick-detach and -attach devices.

f. Space Environment Protection. Because of the fluidity of the spacecraft and telescope configurations during this conceptual study, the effects of space environment have not been analyzed in detail. It appears, however, that damage from micrometeoroids, radiation, and other similar effects will not be a problem in operating for a two-year period. Protective shields have been provided as an integral part of the Propulsion/Support Module and form an external shell for the two-year period. Additional protection will not be needed if the PSM is replaced as a unit each two years (as proposed in Section 3.5.4.1d).

The equipment mounted on the ATM Rack may require some additional protection for the two-year operating period and more for the 10-year period. Each of the exposed components on the Rack must be separately investigated to determine its environment-resistant capability. Because of the shadowing effects of the solar arrays, the telescope, and the PSM, and ATM Rack will have comparatively small statistically exposed areas. These may require covering with shields or exposed components may be fitted with heavier covers.

The telescope structure, with the current single-shell concept, may require special shielding. As discussed in Section 3.4.1 additional shielding can be added as part of the integral shell structure with no increase in weight (using a sandwich-type structure). Before such changes are introduced, however, a detailed analysis should be made, not only of the damage potential versus operating time, but also of the effects of the damage. For example, small punctures in the telescope shell may be quite acceptable and not alter the optical/astronomical function to any measurable degree. Further, small particles passing through the outer shell may, statistically, not strike any of the critical optical surfaces. On the basis that simple structural repairs can be made and optical element replacement accomplished by astronauts periodically after the initial two-year period (and possibly during the period), careful evaluation of the usefulness of added protection should be made.

3.5.4.2 Reliability Characteristics of the LTEP System. The features described following have a significant effect on the functional reliability of the LTEP system. Detailed numerical analysis of the subsystems and their components will be accomplished in the follow-on study phases as the elements of the subsystems and their interfaces are more specifically determined as a result of preliminary system design.

a. Basic Structure. The structure of the telescope and PSM will be designed to the same criteria as used by NASA for other manned systems. The telescope structure will be designed not-to-yield rather than not-to-fail under applied loads. This will assure no permanent deflections which could directly and adversely affect optical alignment. Historically, structure has been listed having a 0.9999 reliability. LTEP system structures should be no exception. No wear out or fatigue mode exists in the planned structural approaches because the portions sustaining oscillating or repeating loads will be overdesigned to prevent deflection; the telescope tube is the primary example of this type of structure.

b. Pyrotechnic Devices. Most, if not all, mechanical unlatch or release functions will be performed by ruggedly-designed structural elements and powered by redundant pyrotechnic power sources. Duplicate pyro charges will be provided in each device; either charge properly ignited can separately power the mechanical function. Duplicate ignition devices will be provided in each pyro charge capsule, thereby assuring proper ignition. These devices are also rated in the 0.999+ reliability category. This high reliability is required, however, because several of these functions are performed in sequence during the orbit deployment operation (see Section 3.2.3 for sequence of events).

c. Telescope Extension. The primary proposed mode of launch-caging and telescope extension combines the various capabilities of the screw-jack extension system (described in Section 3.3.1). The most reliable approach envisions a set of four irreversible-screw extension posts. In the retracted position, the posts would hold the telescope sections in a rigid launch-stowed position, providing hold-down preload.

Actuation of the extension-drive motors would extend the two movable sections. The gear boxes of the four drive motors are interconnected by a direct drive flex shaft to provide synchronous movement and drive by all or only one of the motors. The motors are clutched to the gear boxes to provide disconnection of any failed motors, allowing the remaining motors to drive the four extension screws. The motors will be sized to allow a single motor to extend the telescope sections. The screw-jacks will drive against mechanical extend-stops, thereby locking the telescope in the extended position. As an additional precaution, provisions for manual cranking are installed at the bear boxes to allow an astronaut to handcrank the telescope open if motor power circuits fail.

The approach described offers extremely high reliability and eliminates sequenced unlatching, drive, and latching operations.

d. Propulsion and Attitude Control System. The propulsion subsystem has a completely redundant pressurization and feed system. The individual thrusters (16) are totally redundant also and are arranged so that the vehicle orientation can be maintained by only one set (8) of the thrusters operating.

As mentioned previously, the CMGs are partially redundant, in that any two of the three can provide platform stabilization. Required redundancies will be incorporated in the fine-pointing control electronics to obtain the target reliability for the control system.

e. Electrical Power Subsystem. The extension of the solar arrays will be accomplished by latch release (pyrotechnic device) and mechanical spring extension, both basic functions having been frequently tested on many programs and having high reliability. The periodic rotation of the solar arrays by electromechanical devices has a lower-level reliability than the one-shot deployment. Tentatively, it is planned to have redundant motors driving each rotation gear box, with either motor capable of driving the solar array to the required position. Interconnecting the gear boxes of the two drive mechanisms (one for each solar array wing on the ATM) may be desirable but will not be proposed until some detailed statistical analysis has been performed on the duty cycles and basic motor reliability characteristics under the on-off cycling mode. Override control of the servo-loop array positioner will be provided for remote command from the Cluster (via hard-line) and from the ground station (via RF). The solar array/battery charge control and distribution circuitry is quite reliable and, if necessary, can be made further redundant to obtain a higher reliability characteristic

3.5.4.3 Quality Assurance Objectives. In the implementation of the LTEP system, special activity will be necessary to control materials, fabrication processes, handling techniques, and testing to assure that the LTEP Module launched into orbit retains all of the characteristics required for proper long-time orbit operation. A few of the highlight examples are given; a complete quality assurance plan will be prepared during follow-on studies.

a. Cleanliness Plan. A specific plan must be established setting forth requirements and implementing procedures for maintaining extreme cleanliness of all hardware, from raw material to finished LTEP Module. Every effort must be made to prevent accumulation of dirt or other foreign matter on elements of the Module, particularly within the cavities housing optical elements. Very special care must be exercised also in handling of critical surface materials. Included are thermal-control surfaces as well as the optical surfaces. The importance of cleanliness and control of other contaminants, as discussed in the following paragraph, is emphasized with respect to operation in the presence of particles as described in detail in Appendix A.

b. Control of Other Contaminants. Oils, greases, and other space-volatile substances must be meticulously avoided. Processing control must be exercised to prevent accumulations of water or other volatiles within or on materials. Post-processing, such as vacuum baking to remove volatiles or subliming materials, must be strictly monitored and process sampling performed frequently.

c. Packaging and Handling. All critical elements must be carefully packaged and protected in sealed containers during all handling operations external to clean-room assembly and testing. All container openings should be recorded and the items, when out of containers, placed under surveillance to assure no mishandling.

d. Alignment. The assembly of all structural elements contributing to telescope alignment must be carefully supervised. All drive mechanisms, mechanical stops, and other devices affecting erection and alignment must be thoroughly ground-tested under loading conditions (and simulated jamming) exceeding those which may occur in orbit.

e. Extent of Quality Assurance Surveillance. The inspection, monitoring, and recording functions of quality assurance are not planned to be limited to the initial fabrication and assembly operations. Detailed inspection, preceding and following inter-facility transportation, will be scheduled and special surveillance in test facilities and at the launch base will be applied. The telescope assembly will be sealed in the launch-stowed configuration prior to shipment to the launch base and will remain sealed until launch. To prevent "breathing" and entry/entrapment of water vapor, the inner cavity of the telescope may be pressurized with inert gas (nitrogen or helium). Internal telescope cavities will be monitored remotely from transducers mounted in the cavities.

Section 4

ALTERNATE SPACECRAFT MODES

4.1 SYSTEM APPLICATION

The LTEP Module has been conceptually designed to be applied to one of four basic missions. They are illustrated in summary form in Fig. 60 as Modes 1 through 4. The basic or baseline approach (Mode 1 mission) is described in Section 2.3. Section 3 described the baseline LTEP Module and its equipment. The following paragraphs will outline the launch configurations, the special operating features (as they differ from the baseline), and the parts/weight breakdowns for additional hardware elements for Modes 2, 3 and 4. In addition to these implementation variation possibilities, the basic LTEP Module is readily adaptable for use with the Space Shuttle and/or the space station as discussed in Section 2.3.6.

4.2 THE TITAN IIIC LTEP (MODE 2 – INDEPENDENT/UNMANNED)

This mode provides for launch on a Titan IIIC of an LTEP Module which, when released in orbit, will operate independently of any other on-orbit system.

4.2.1 Titan IIIC Launch Configuration

The launch configuration of the LTEP Module atop the Titan IIIC launch vehicle is shown in Fig. 61. The elements are described as follows:

a. Adapter. A short truss-frame adapter will be provided. It will be bolted at eight places to the 120-inch diameter support ring strong-points on the IIIC launch vehicle). The upper ring of the truss-frame will mate with the LTEP Propulsion/Support Module. Four sets of springs and pins mounted at 90 deg will provide rigid attachment of the Transtage and LTEP Module during launch and ascent and will provide separation forces upon release. Pyrotechnically actuated pin pullers will be used to release the four attachments following payload fairing jettison.

b. LTEP Module. The LTEP Module, except for the Transtage adapter mountings, will be identical to the baseline module described in Section 3. It will comprise the Telescope Assembly, the modified ATM Rack, two ATM solar arrays, and the Propulsion/Support Module.

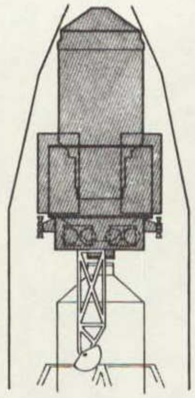
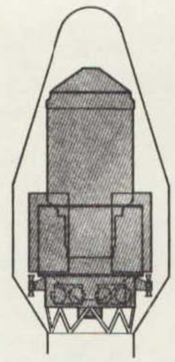
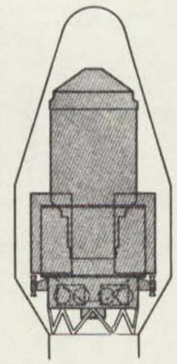
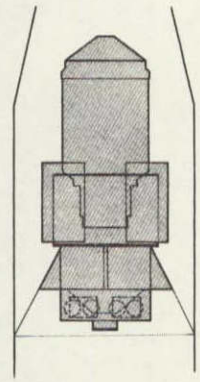
MODE →	THE SWS-II LTEP ① AAP SATURN WORKSHOP	THE TITAN IIIC LTEP ② INDEPENDENT UNMANNED	THE RENDEZVOUS LTEP ③ INDEPENDENT LAUNCH CLUSTER OPERATION	THE SATURN IB LTEP ④ INDEPENDENT LAUNCH MANNED CAPABILITY
LAUNCH ENVELOPE				
LAUNCH VEHICLE	SATURN V	TITAN IIIC	TITAN III C	SATURN IB
SYSTEM EQUIPMENT	2 METER TELESCOPE ATM RACK PROPULSION/SUPPORT MODULE	SAME AS MODE 1	SAME AS MODE 1	SAME AS MODE 1 PLUS MOTEL
MANNED SUPPORT	AAP SATURN IB LAUNCH	NONE	AAP SATURN IB LAUNCH	SATURN IB LAUNCH
KEY FEATURE	INTEGRAL CLUSTER EXPERIMENT	UNMANNED SIMPLIFIED EXPERIMENT	AAP EXPERIMENT AUTONOMOUS LAUNCH	AUTONOMOUS-MANNED SUPPORT CAPABILITY

Fig. 60 LTEP System Applications

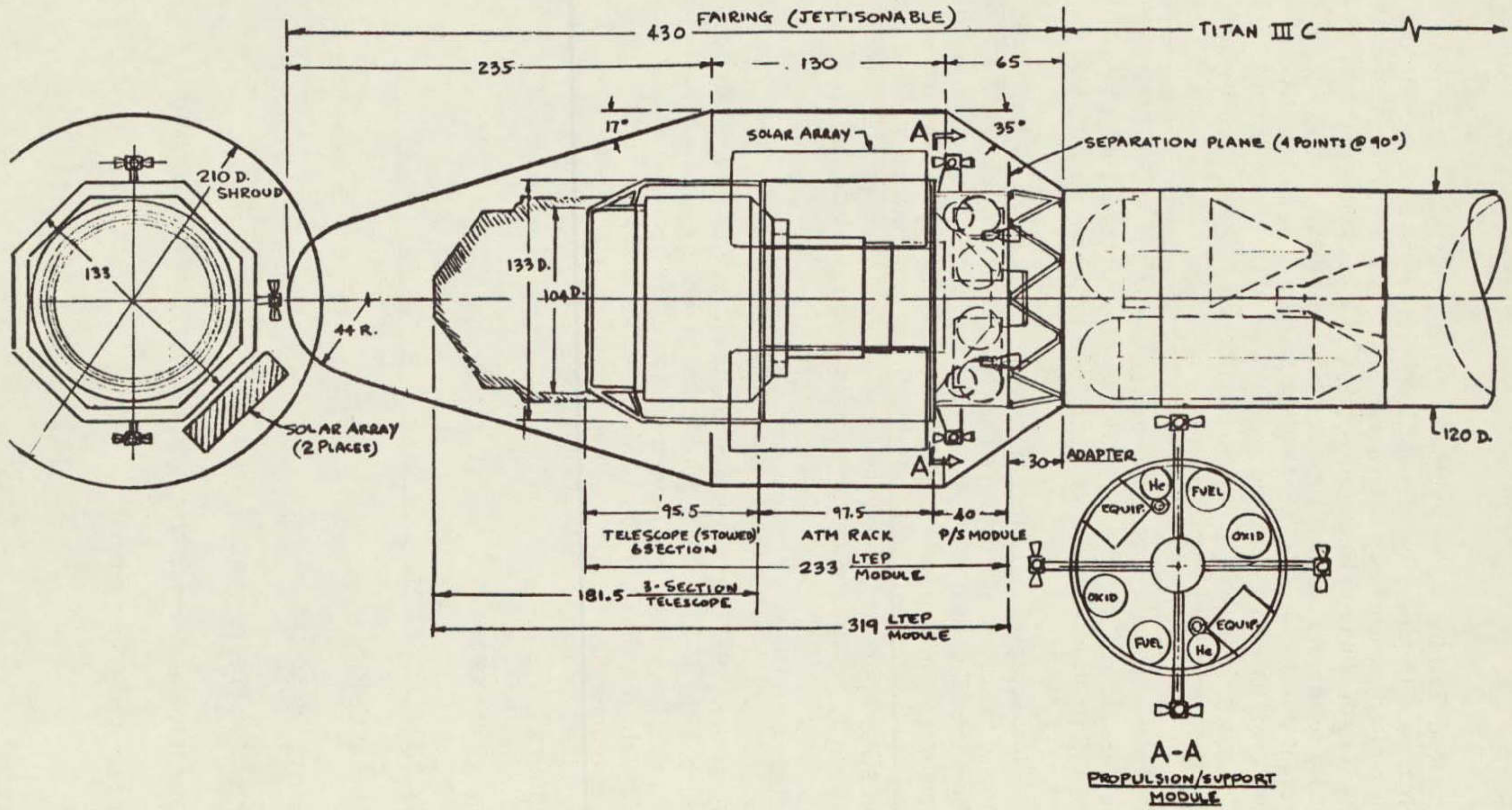


Fig. 61 Titan IIIC Launch Configuration

c. Payload Fairing. The payload fairing is a typical hammerhead. To provide clearance for the stowed-position solar arrays, a cylindrical section diameter of approximately 210 inches is required. The ratio of the diameter to the length of the cylindrical section is a parameter which, historically, has had a minimum slightly smaller than proposed. However, for reasons of weight conservation, the shortest fairing compatible with internal clearances was tentatively established. If proved to be unacceptable aerodynamically, the cylindrical section can be lengthened without affecting the LTEP system (except increased launch weight).

The forward cone portion of the fairing is the standard preferred by Titan vehicle launch integration. The 35 deg reverse cone taper to the Titan 120-inch diameter is within Titan payload envelope specifications.

The total fairing is to be constructed in three equal longitudinal sections. A linear charge is placed along each of these mating section lines and around the base (120-inch diameter). When proper altitude has been reached during ascent (when air loads are considerably reduced), the linear charge is ignited and the fairing will split into the three separate elements as it is jettisoned. Small gas jets at the forward end of each element will force that piece radially outward, rotating about a restraining hinge at the aft end (Titan interface).

4.2.2 Orbital Operation

The launch, ascent, and orbit erection sequence will be essentially the same as for the Saturn V launch, the sequence for which was given in Section 3.2.3. The Titan IIIC upper stage, the Transtage, will separate from the basic booster vehicle and transport the LTEP Module into initial orbit position. The payload shroud will be jettisoned after attainment of a specified altitude. Upon reaching orbit position, the LTEP Module will release from the Transtage and execute sequenced operations automatically or by ground-control command:

- Deploy antennas
- Deploy solar arrays
- Spin-up CMG's
- Extend telescope
- Activate pointing control system
- Complete coarse-pointing with attitude control thrusters
- Uncage telescope gimbal

4.2.3 Configuration Summary

The orbit configuration of the LTEP Module is as shown in Fig. 62 and is identical to Mode 1 in the Independent operation. The weight of the truss-frame adapter required between the LTEP Module and the Transtage has been estimated at 200 lb. The weight of the payload fairing has been estimated at 2000 lb.

4.3 THE RENDEZVOUS LTEP (MODE 3 – INDEPENDENT LAUNCH/CLUSTER CAPABILITY)

This mode provides for launch on a Titan IIIC of an LTEP Module which will, after attaining orbit, rendezvous with an AAP orbiting Cluster and dock thereto for experiment operations.

4.3.1 Launch Configurations

The launch configuration is identical to that described in Section 4.2.1.

4.3.2 Orbital Operations – Docking

Upon attaining orbit altitude and separating from the Transtage upper stage booster, the LTEP Module will be commanded to maneuver and move slowly toward physical rendezvous with the orbiting AAP Cluster. The Module will be under simultaneous surveillance and command direction by RF from the ground station and from the Cluster.

When the Module reaches a predetermined distance from the Cluster, complete command will be relinquished to an astronaut(s) in the Cluster MDA. A docking maneuver will be completed and the Module docked into a radial docking port on the MDA (opposite the normal deployed position of the ATM Rack). If the LTEP Module CMG's are used for platform stabilization during free-flight and during the rendezvous/docking maneuvers, they must be switched off subsequent to docking to the Cluster. It is presumed that Cluster CMG's will be operating prior to the docking. The sequence of operations for docking to the Cluster is listed in Table 16.

4.3.3 Configuration Summary

The rendezvous radar antenna and transponder required for the docking maneuver are planned as standard components within the Guidance/Navigation/Control subsystem of the Module. They will also be used for rendezvous and docking with the CSM or the Space Shuttle. Except for the Apollo probe mounted in the Propulsion/Support Module docking tunnel, the Mode 3 configuration is identical to Mode 2. The docking probe assembly will add approximately 35 lbs to the total LTEP Module, making its launch weight 21,600 lbs. The Titan launch adapter and the payload fairing also are identical to Mode 2, weighing respectively 200 lb and 2000 lb.

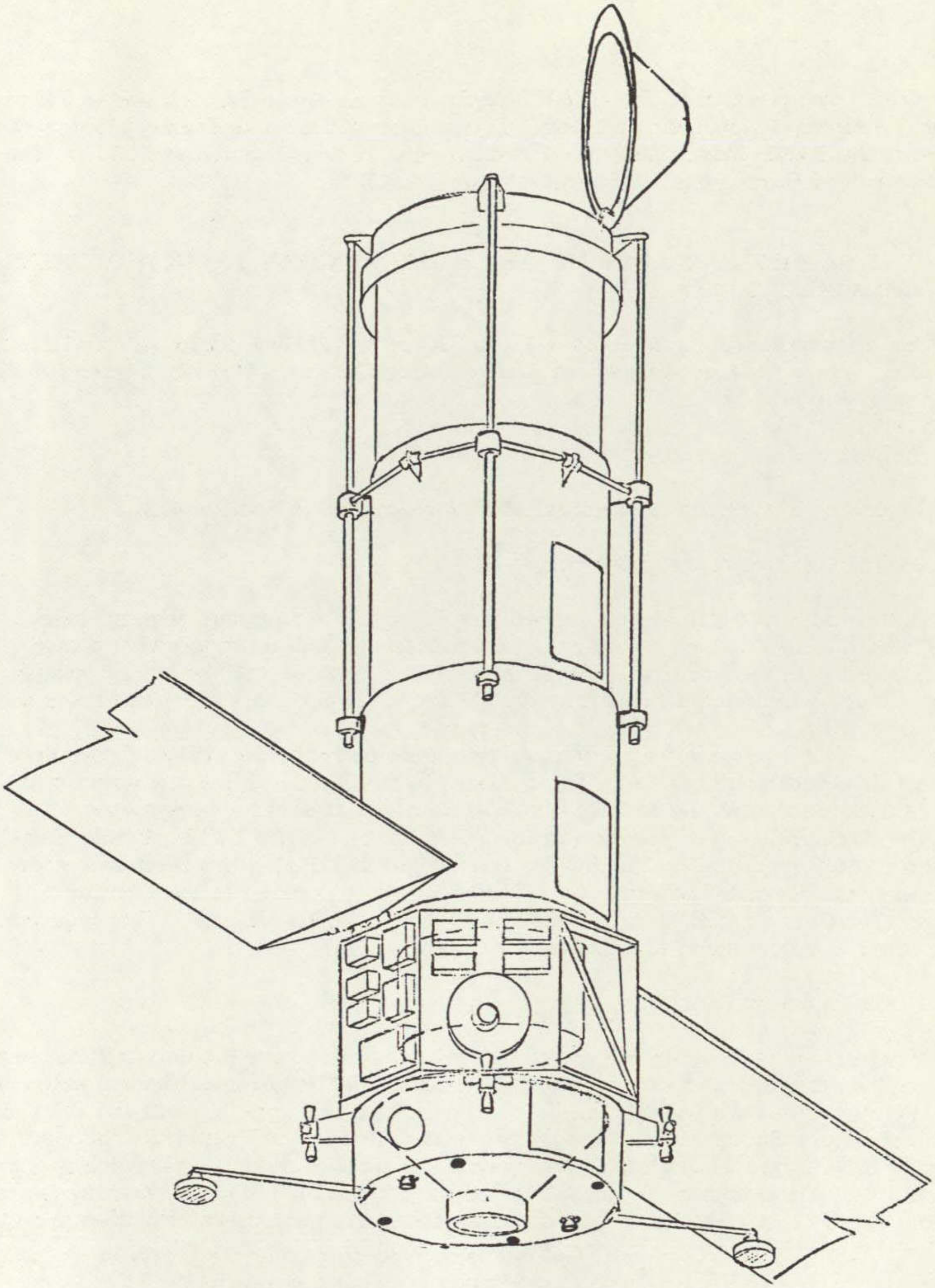


Fig. 62 Independent LTEP Module — Orbit Configuration

Table 16

DOCKING AND ERECTION SEQUENCE FOR
INDEPENDENT-LAUNCHED LTEP MODULE

1	LTEP Module and Cluster rendezvous using radar transponder on Module and astronaut command from Cluster via RF
2	Dock Module into MDA port using the Apollo probe on the LTEP Propulsion/Support Module into the drogue cone in the MDA port
3	Astronaut will fix inner latches on mated docking ring (access through MDA tunnel) providing rigid attachment of Module to Cluster
4	Astronaut will manually connect electrical interconnect at docking tunnel interface
5	Deactivate CMG's on Module
6	Deploy solar arrays on Module
7	Extend telescope

4.4 THE SATURN IB LTEP (MODE 4 – INDEPENDENT/MANNED)

This mode provides for launch on a Saturn IB of an LTEP Module coupled with a man-cell (MOTEL). After docking in orbit with an Apolla CSM, the MOTEL will provide short duration housing for an astronaut performing simplified monitoring and control experiments with the telescope.

4.4.1 Saturn IB Launch Configuration

Figure 63 is an illustration of the Saturn IB launch configuration for the Independent LTEP/MOTEL Module. The MOTEL is installed between the ATM Rack and the PSM. The total module will be supported by four web-outriggers on the MOTEL to four points on the forward ring of the cone adapter. The module will be separated from the SIVB upper stage at these four points following payload fairing jettison. The elements are described following:

a. Adapter. The adapter is a fixed conical structure 62 inches long attached to the SIVB at the aft end ring (260-inch diameter). Structural reinforcing at four points (at 90 deg) on the forward ring will distribute the point loads into the cone shell. Separation fittings will be provided at these four points to accept pins of the four webs on the MOTEL. Pyrotechnic devices (pin pullers) will release the module upon remote command.

b. Payload Fairing. The payload fairing is identical to that planned for use with the AAP Dry Workshop Cluster payload (on a Saturn V launch).

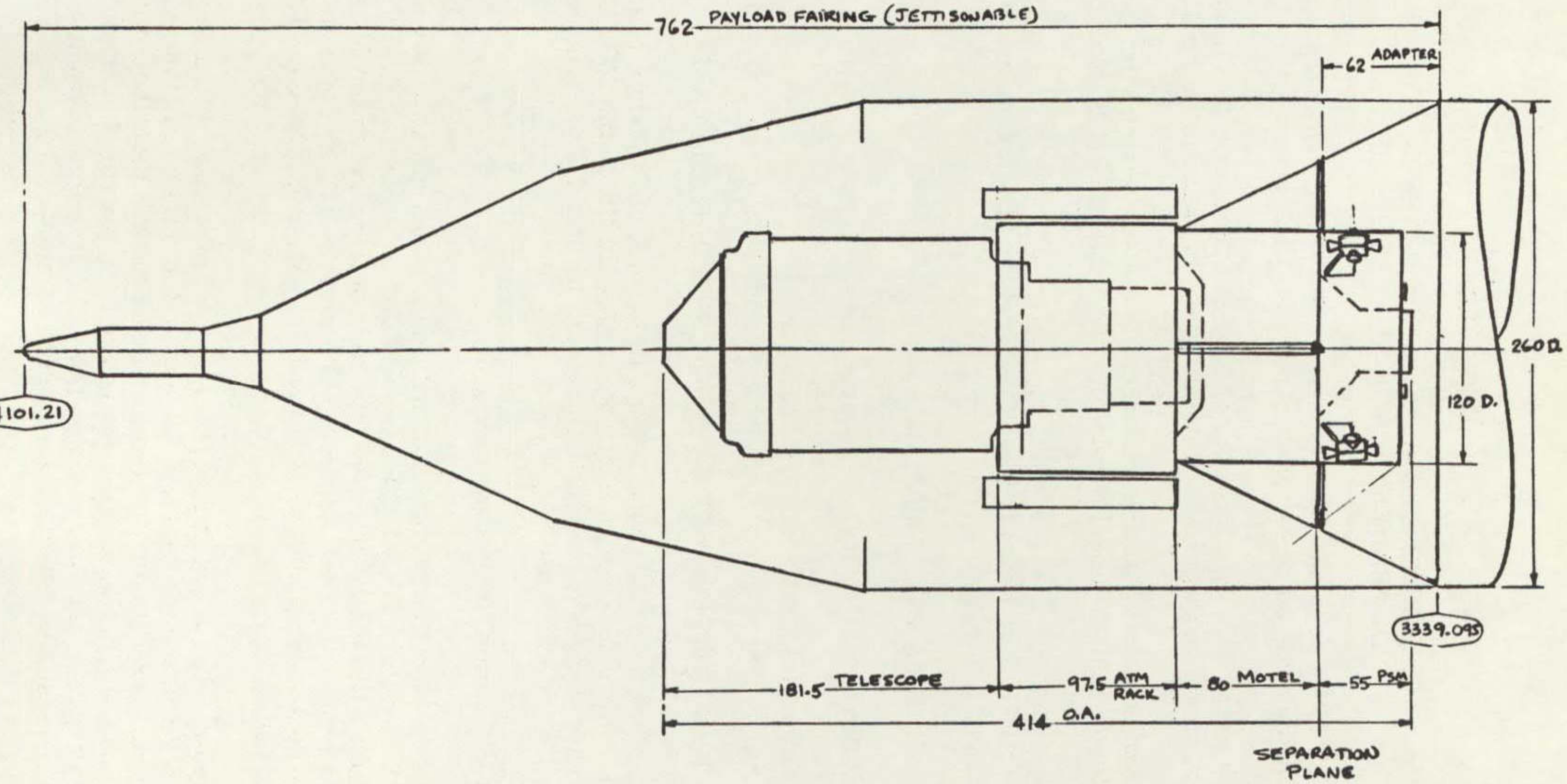


Fig. 63 Saturn IB Launch Configuration

c. LTEP/MOTEL Module. The LTEP Module elements are identical to the baseline except for minor structural adapations to accept installation of the MOTEL; the MOTEL itself is described in following paragraph.

4.4.2 Manned Orbital Telescope Experiment Laboratory (MOTEL)

The MOTEL is a simple structural shell, capable of pressurization to approximately 5 psi, and with minimum crew provisions to aid an astronaut in performing simple experiments in conjunction with the LTEP telescope. Although control and display equipment can be elaborated to any level of sophistication desired, the conceptual design currently envisions (1) a small display panel, containing display of major telescope experiment parametric readouts (perhaps including TV image of telescope field-of-view), and (2) a simple control panel which will allow the astronaut to select basic operating modes, to select experiment readout channels, and possibly simple controls for placing biases in the fine-pointing control loop for gross stellar field selection.

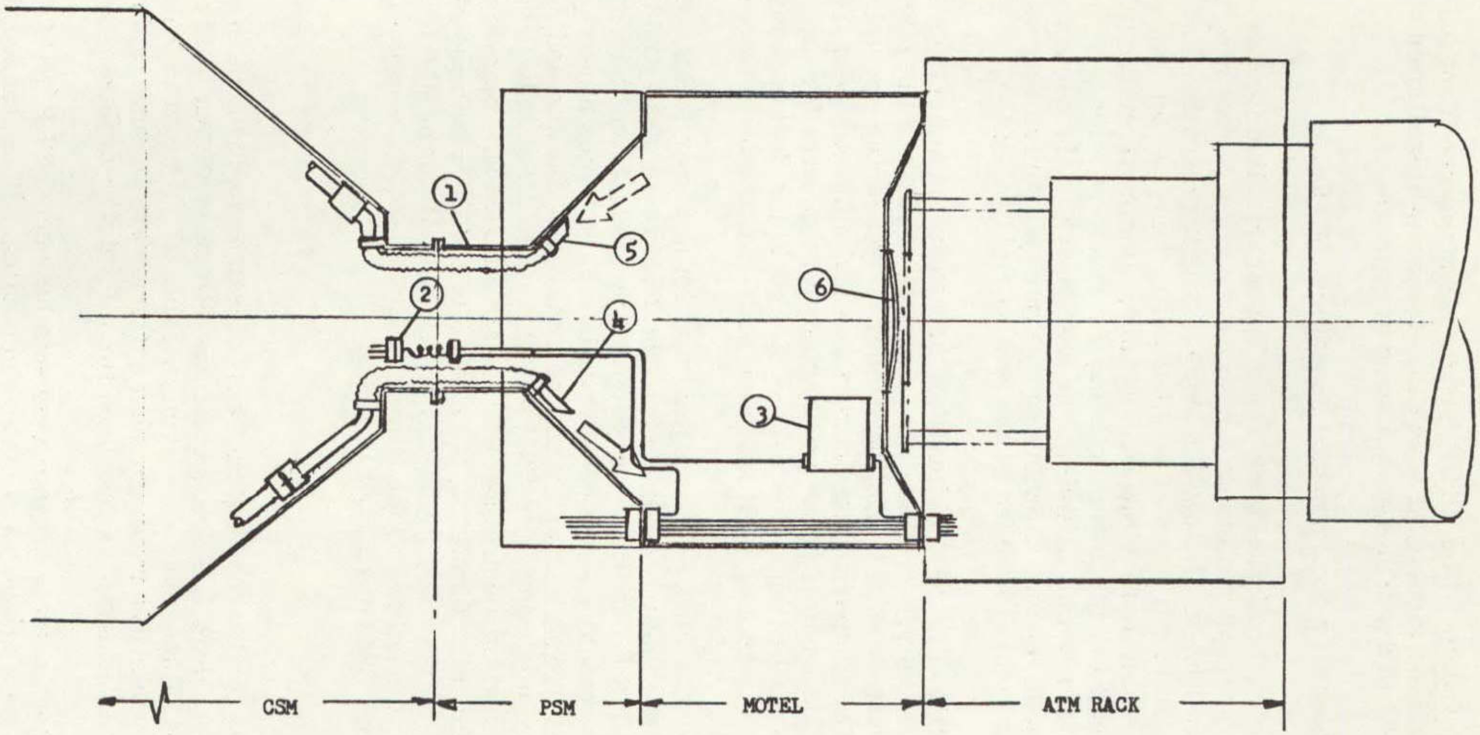
Handholds and tethers will be provided to facilitate astronaut movement. A set of cabin lights for internal illumination will be installed. Seats or bunks are not planned because of the short duration (perhaps 3 or 4 hours) occupancy. Open-hatch operation with the docked CSM is planned with compartments pressurized and a blower-duct from the CSM supplying replenishment life support gases and temperature control for the MOTEL. Temporary hardline electrical connections will be stowed in the docking tunnel and manual connections made by the astronaut after the pressure hatches are opened.

A schematic illustration of the MOTEL docked to the CSM is shown in Fig. 64. The full cavity of the MOTEL and the inner conical shell of the PSM form a gas-tight enclosure. After the CSM is docked, the PSM will be pressurized by gases from the CSM (via a valve in the docking tunnel hatch). When pressures in both volumes have equalized, the tunnel hatch and the probe/drogue assembly will be removed. Blower and return ducts will be taken from stowage position in the CSM and clipped in place onto brackets provided in the PSM. Electrical connection between PSM and CSM will be made by the astronaut in the docking tunnel, completing the hookup of the CSM with the MOTEL. A hatch with a porthole will be provided in the end of the MOTEL facing the telescope. This hatch may be opened for access to the bottom of the telescope equipment bay (after pressure is reduced in both CSM and MOTEL).

4.4.3 Orbital Operation

The operational sequences for launch, ascent, and telescope deployment in orbit are the same for Mode 4 as for Mode 1. The special operations involving CSM docking and MOTEL occupancy by an astronaut are given in Table 17. One area which has not been investigated is the capability of the extended solar arrays to sustain the loads resulting from docking. An analysis is proposed for the follow-on Phase B.

In consideration of astronaut safety, all interconnects between LTEP/MOTEL and CSM must be quickly detachable or provide automatic-decoupling. It is planned that the electrical connector be a breakaway type where a quick pull on a lanyard release will separate the spring-loaded halves. Also, the clips for the ventilation ducts attachment



1. DOCKING TUNNEL
2. BREAKAWAY DISCONNECT (STOWED IN PSM AND MANUALLY CONNECTED BY ASTRONAUT)
3. DISPLAY/CONTROL PANEL
4. BLOWER DUCT - CONDITIONED BREATHING GAS (STOWED IN CSM AND MANUALLY CLIPPED ONTO PSM)
5. RETURN DUCT (STOWED IN CSM AND MANUALLY CLIPPED INTO PSM)
6. HATCH IN PSM FOR ASCESS TO CENTRAL COMPARTMENT OF TELESCOPE EQUIPMENT BAY (MOTEL AND CSM UNPRESSURIZED WHEN HATCH IS OPENED).

Fig. 64 Arrangement of CSM Docked to LTEP/MOTEL Module in the PSM must be detachable with a light load (perhaps magnet-mounted to small plate on structure). Emergency equipment, including fire extinguisher, first aid, and emergency light, will be stowed in the MOTEL.

Table 17

DOCKING AND PREPARATION OF MOTEL OPERATION SEQUENCE

Step	Sequence Operation
1	LTEP/MOTEL Module commanded to cage the telescope
2	LTEP/MOTEL Module commanded to hold a specific orbit attitude (CMG's will stabilize the platform inertially)
3	CSM will rendezvous with and dock to PSM docking ring; mating CSM probe with PSM drogue cone
4	Valve in CSM tunnel hatch will be opened, releasing gases to MOTEL cavity. Pressure in MOTEL will be raised until equal to CSM
5	Pressure will be monitored to assure no excessive leakage in MOTEL
6	Astronaut opens CSM tunnel hatch and removes and stows probe and drogue cone
7	Astronaut manually closes docking ring latches
8	Astronaut removes ventilating ducts from stowage in CSM and clips into mounts in PSM
9	Astronaut connects electrical connector in tunnel area, interconnecting LTEP/MOTEL and CSM

4.4.4 Configuration Summary — Mode 4

The overall flight configuration of the LTEP/MOTEL Module is shown in Fig. 65. The basic envelope dimensions and a component and weights breakdown are discussed following.

a. Envelope Dimensions. The overall dimensions of the module are shown in Fig. 66. Detail dimensions of elements are not shown; they are identical to those for the baseline module shown in Fig. 56.

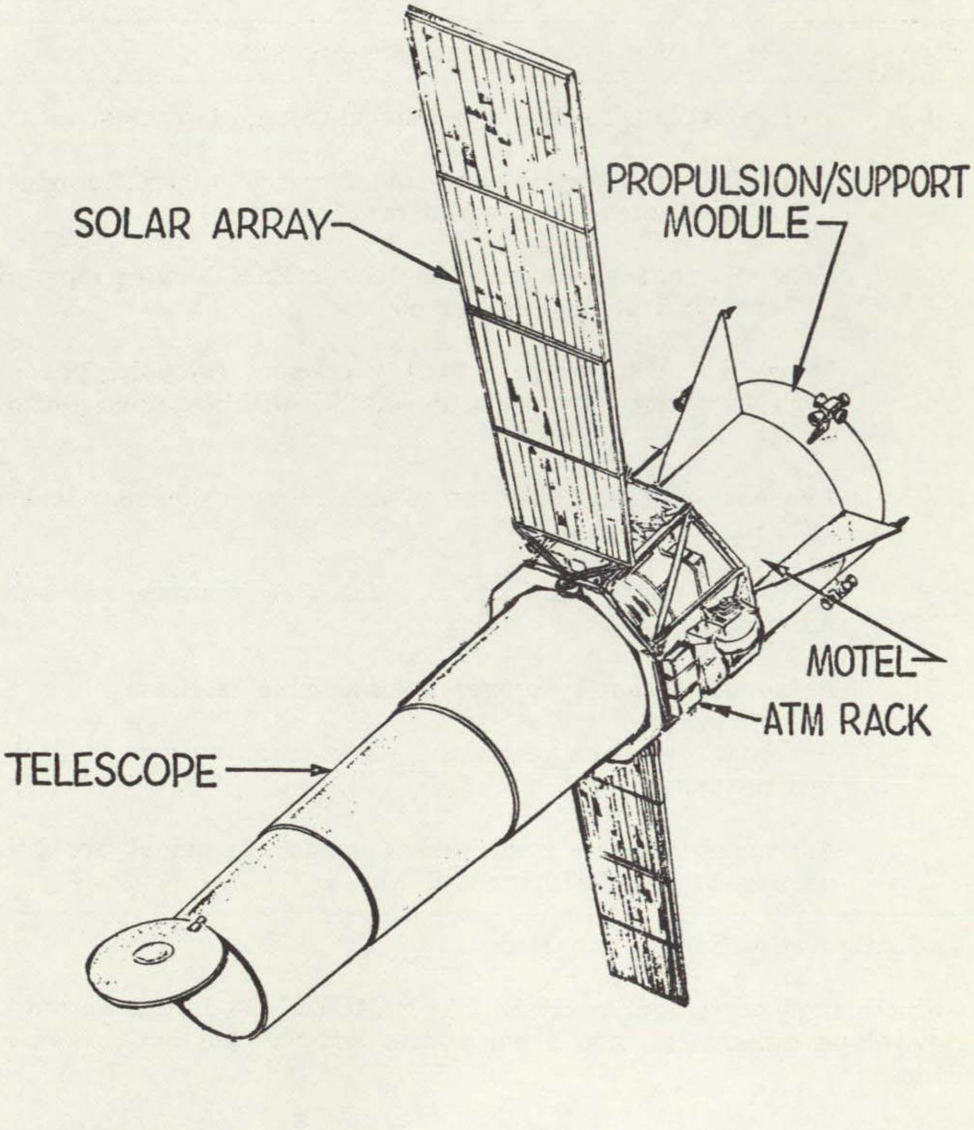


Fig. 65 Orbit Configuration of LTEP/MODEL Module

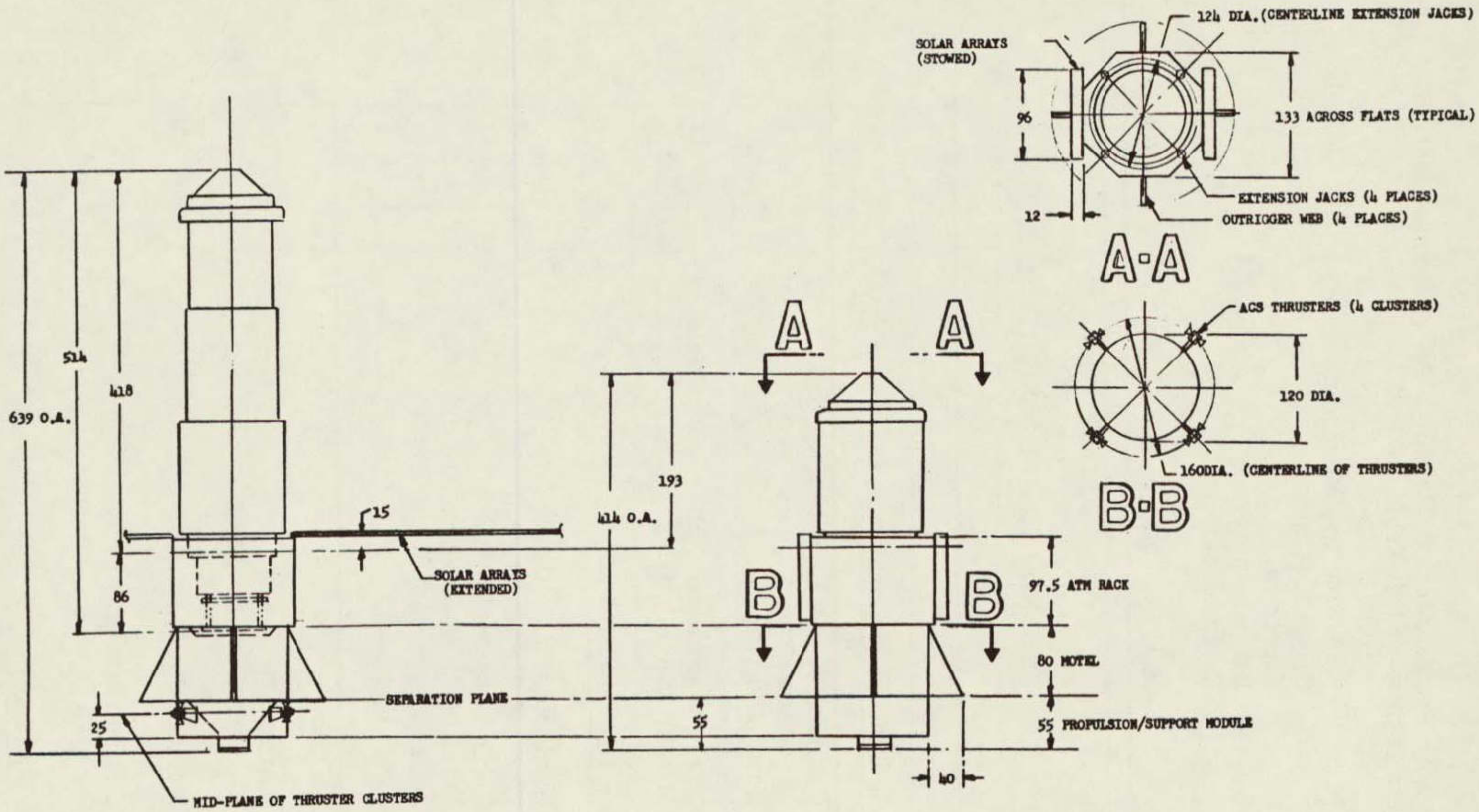


Fig. 66 Envelope Dimensions of LTEP/MOTEL Module

b. Assembly Breakdown and Weights. An equipment list with quantities and weights is provided in Table 18.

Structure and Mechanisms	621 lb
Crew Provisions	67
Electrical	10
Instrumentation	25
Communications	3
MOTEL Total Weight	726 lb

Table 18

BREAKDOWN AND WEIGHTS – MOTEL

Subsystem Element	Qty	Weight (lb)
• Structure and Mechanisms		(621)
Cylindrical shell and outriggers	1	350
Miscellaneous equipment supports	1 set	20
Hatch and ring	2 sets	36
View ports	3	15
Thermal insulation/micromet, shielding	1	185
Miscellaneous attaching parts	1 set	15
• Crew Provisions		(67)
Handholds and tethers	1 set	10
External lights	1 set	5
Cabin (interior) lights	1 set	4
Emergency equipment (fire ext, etc.)	1 set	26
Accessories (maps, etc.)	1 set	20
Tool kit	1	2
• Electrical		(10)
Switch panel	1	5
Electrical interconnect cabling	1 set	5
• Instrumentation		(25)
Control/display panel	1	20
Sensors (temps, pressure, etc.)	1 set	5
• Communications		(3)
Hardline VHE (Voice) hatch to C/D	1	3
TOTAL		726

4.5 ADDITIONAL CONSIDERATIONS

In addition to studies of the Modes 1 through 4 and their application independently and with the AAP Orbiting Cluster, the Space Station, and the Space Shuttle, a cursory inspection of two other telescope applications has been made. The installation of a 3-meter telescope installed in the Space Shuttle appears feasible and is discussed in Section 4.5.1. The elaboration of the MOTEL into a HOTEL for extended-duration manned independent operation has been studied also and is discussed in Section 4.5.2.

4.5.1 3-Meter Telescope in the Space Shuttle

Figure 67 illustrates the outline of a 3-meter telescope mounted in the cargo bay of the proposed space shuttle. Because of the very long extended length of the telescope, the tube is conceived as a three-section retractable arrangement (similar to the proposed LTEP 2-meter concept). This allows the secondary optics support to be a one-piece pre-installed element calibrated to the primary mirror.

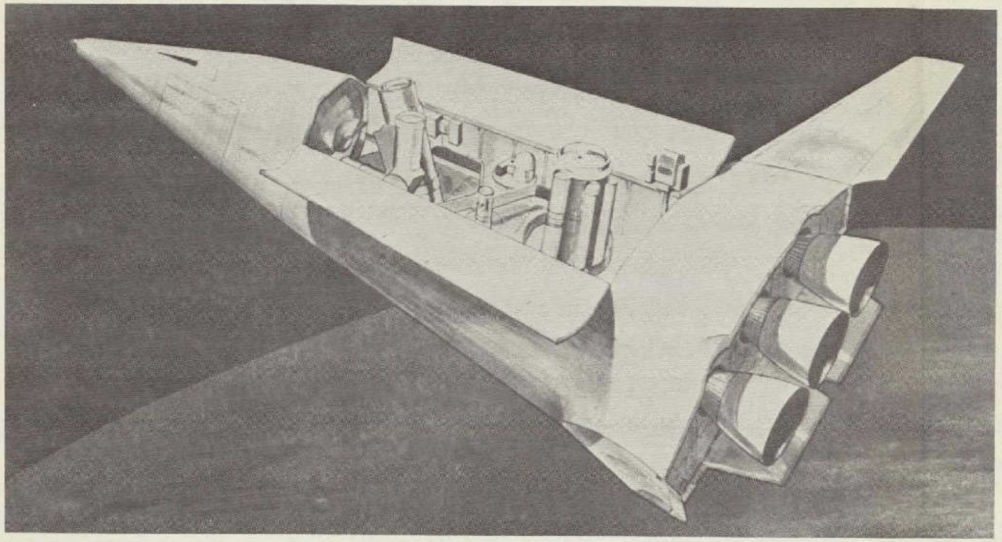
The shuttle could transport the telescope to orbit and deploy and release it to a free-flight condition. An alternate mode would have the shuttle performing as the space platform for the telescope. The telescope would be deployed from the cargo bay on rigid linkage mounted to the shuttle and be erected. In the latter mode, the telescope could be man-controlled; a pressurized and instrumented compartment in the shuttle passenger volume could be utilized. For either the free-flight or the shuttle-attached mode, the rotatable solar arrays would be extended to supply power for long-term (multi-orbit) operations.

Adding an integral man-cell to the 3-meter telescope would require lengthening of the retracted length approximately 100 inches to allow for the added module. There is adequate cargo volume available for this enlargement of the payload.

4.5.2 HOTEL Man-Support Module

In lieu of the MOTEL, which is dependent on the CSM for a pressurized volume in which an astronaut can perform some simple experiments or maintenance operations in a short period of time (2 to 4 hours), a HOTEL module has been conceptually designed which offers long-term astronaut support with complete environmental control and life support subsystems. The basic structural shell is the same; however, crew equipment and expendables are added to allow an astronaut to remain in the completely independent LTEP/HOTEL Module for up to 30 days. Free-flight manned experiments can be performed after undocking of the man-delivery vehicle (a CSM or a Space Shuttle). Re-docking would be accomplished at the end of the manned experiment period; the LTEP/HOTEL Module could then be placed on "automatic" and continue orbit operations.

The astronaut would have voice communication with the orbiting "team" vehicle and with earth via the Communications and Instrumentation Subsystem in the LTEP Propulsion/Support Module; he would be provided also with over-ride command on the primary flight controls of the LTEP Module.



Various approaches to astronomy applications for the Space Shuttle have been considered; the LTEP configuration is a unique, applicable use of the capabilities of this advanced system.

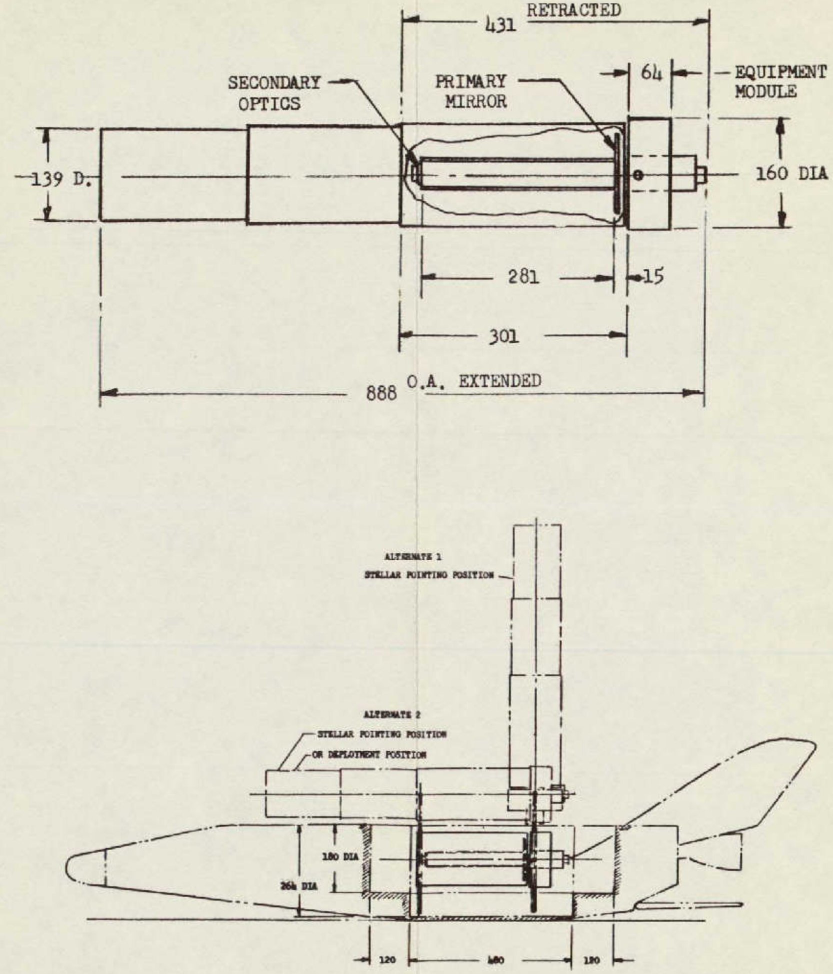


Fig. 67 3-Meter Telescope in Space Shuttle

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The external dimensions of the HOTEL are proposed to be identical to the MOTEL so that a step development approach can be used if desired. The weight of the HOTEL, stocked with expendables for a 30-day independent mission, is estimated to be 2715 lb. The basic breakdown follows; a detail equipment breakdown with weights is provided in Table 19.

- Structures and mechanisms . . . . 654 lb
- Crew provisions 237
- ECS and life support 719
- Electrical 15
- Instrumentation 30
- Communications 3
- Fluids, gases and expendables 1057

Total HOTEL 2715 lb

Table 19

SUBSYSTEM ELEMENTS AND WEIGHTS – HOTEL MODULE

Subsystem Element	Qty	Weight (lb)
• Structure and mechanisms		(654)
Cylindrical shell and outriggers	1	350
Miscellaneous equipment supports	1 set	53
Hatch and ring	2 sets	36
View ports	3	15
Thermal insulation/M. M. shielding	1	185
Miscellaneous attaching parts	1 set	15
• Crew Provisions		(237)
Seat, bunk and restraint harness	1	15
Reel restraint	1	7
Handholds, tethers	1 set	10
External lights	1 set	5
Cabin interior lights	1 set	4
Suit maintenance kit	1	1
PLSS blackpack (spare)	1	100
Food storage/prep. equipment	1	16
Waste management equipment	1	26
Personal hygiene equipment	1	5
Emergency equipment (fire ext., etc.)	1 set	26
Accessories (maps, etc.)	1 set	20
Tool kit	1	2

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Table 19 (Cont.)

Subsystem Element	Qty	Weight (lb)
• Electrical		(15)
Switch panel	1	5
Interconnect cabling	1 set	10
• Instrumentation		(30)
Control/display panel	1	20
Sensors (temp, pressure, etc.)	1 set	10
• Communications		(3)
Hardline VHF (C/D panel to hatch)	1	3
• Environmental Control and Life Support*		(719)
Suit circuit (LM)	1	110
Cabin recirculation (LM)	1	19
Heat transfer section (LM)	1	34
Oxygen module (LM)	1	17
Radiator and plumbing	1	150
Water management (LM)	1	21
Plumbing	1 set	60
LO_2 tank and plumbing (additional) GEM-RSS, 22 dia	2	170
LN_2 tank and plumbing (additional GEM-RSS, 22 dia	1	85
H_2O tank (additional) LM-D bladder, 29 dia	1	53
• Fluids, Gases, and Expendables*		(1057)
Coolant, ECS		37
LO_2 – metabolic, repress., PLSS refill, leakage)		226
LN_2 – repress., leakage makeup		254
H_2O – drinking, food mix, sanitation		254
LIOH cartridges – cabin (7.5 lb ea)	18	129
LIOH cartridges – PLSS refill (3.6 lb each)	3	12
Batteries – PLSS spares	2	10
Food		60
Personal hygiene supplies		75

*NOTE: Tankage and expendables are for a 30-day period in orbit, supplying one astronaut. This allows two unpressurized IVA's per month with PLSS and attendant repressurizations of HOTEL volume.

Table 19 (Cont.)

Subsystem Element	Qty	Weight (lb)
• Electrical		(15)
Switch panel	1	5
Interconnect cabling	1 set	10
• Instrumentation		(30)
Control/display panel	1	20
Sensors (temp, pressure, etc.)	1 set	10
• Communications		(3)
Hardline VHF (C/D panel to hatch)	1	3

Section 5

SUPPORTING PROGRAM ANALYSES

In the development and evolution of the recommended LTEP concept described in the preceding sections, critical areas were examined in detail to verify the feasibility of implementing the baseline approach. These support areas were as follows:

- Launch Vehicles and Orbit
- Thermal Analysis
- Astronaut Participation
- Resources Analyses

The resources analyses included a preliminary technical plan, subsystem resources plan, facilities plan, test plan, schedule plan and cost plan.

In addition to these four feasibility support analyses, the results of which are provided in the following paragraphs, consideration was given to the potential effects of outgassing and/or contaminants about the spacecraft; this study is summarized as Appendix A. Orbit mechanics parameters are provided in Appendix B.

5.1 LAUNCH VEHICLE SELECTION AND ORBIT PARAMETERS

Fifteen (15) launch vehicle configurations were identified as potential candidates for boosting the LTEP module to a circular orbit at 220 nm altitude and inclined 35 deg, the reference orbit. The four LTEP operation modes and their corresponding configurations were considered; thus the launch vehicle comparisons and selections were made with respect to these configurations. The recommended boost vehicles for the LTEP implementation are as follows:

Mode/Configuration	Launch Vehicle Selection	Launch Vehicle Alternate
1. The SWS-II LTEP (AAP Cluster)	AAP Saturn V*	Saturn IB*
2. The Titan IIIC LTEP (Independent/Unmanned)	Titan IIIC	Saturn 1B
3. The Rendezvous LTEP (Independent/Cluster)	Titan IIIC	Saturn IB
4. The Saturn IB LTEP (Independent/Manned)	Saturn IB	Intermediate 20
*Base program launch vehicle system.		

Preliminary payload weight requirements for the four LTEP operating modes are given in Table 20. If the launch of a manned CSM is to be considered as part of the same

Table 20

LTEP LAUNCH WEIGHT SUMMARY

MODE	1. The SWS-II LTEP	2. The Titan IIIC LTEP 3. The Rendezvous LTEP	4. The Saturn IB LTEP (Independent/ Manned)
LAUNCH VEHICLE	SATURN V (DWS-2) (SIC + SII)	TITAN IIIC	SATURN IB (SIB + SIVB)
• *Payload fairing (jettisonable)	1,125 lb (4500)*	500 lb (2000)*	1,125 lb (4500)*
• Adapter – upper stage	–	200	600
• Adapter – fairing extension	1,500	–	–
• Launch vehicle mods	650	–	650
• LTEP module lb • Telescope 8096 • Propuls/support mod 3965 • ATM rack 8150 • Solar Arrays (2) 2035 • MOTEL (Mode 4 only) 726	22,246	22,246	22,972
• Contingency	1,000	1,000	1,000
Total Launch Weight	26,521 lb	23,946 lb	26,347 lb

*Total fairing weight shown in parenthesis. 25 percent accountable to launch vehicle capability as result of jettison of fairing after attaining low "Q" in upper atmosphere.

launch, (without dependence on the CSM for ascent propulsion), approximately 35,000 lb is added to the given LTEP module weight to establish the total requirement.

A list of candidate launch vehicles with their respective capabilities is presented in Table 21. The orbit chosen for this comparison is circular at 220 nm and inclined 35 deg to the earth's equator. Although the space station mode may employ a slightly different orbit (e.g., 270 nm altitude inclined 55 deg or 300 nm altitude, inclined 50 deg), the baseline orbit requirement (V_{ch} = 26,110 ft/sec) was assumed for the four principal modes. (Space Station and/or Space Shuttle platform applications would utilize the Space Shuttle cargo bay capability to achieve orbit.) Launch vehicles with payload capacities to the 220 nm reference orbit below 15,000 lb (e.g., Atlas/Centaur) were not included since this capability is considered as significantly insufficient for the LTEP mission. The primary source for the performance capabilities is the data contained in Reference 7-23 NASA/OSSA document, "Launch Vehicle Estimating Factors" dated January 1969). The launch vehicles are ranked according to their capabilities to the reference orbit and a discussion of each is given below. The mechanics of the reference orbit are described in more detail in Appendix B.

1. Titan IIIC. The Titan IIIC is a four-stage vehicle that uses two 120-inch, five-segment solids attached to the two-stage Titan II core, plus a pressure-fed liquid-fueled Transtage. The thrust of the solid at liftoff is about 2 million pounds. The Titan IIIC can be used for launching the lightest LTEP module configurations (i.e., Modes 2 or 3 at $\approx$ 23,000 lb), but could not launch the manned CSM to orbit. The 120-inch diameter of the Transtage will require a slight hammerhead to the configuration to accommodate the Independent mode LTEP. This low cost system has some growth capability (margin) and can perform the launch of the unmanned autonomous application with a minimal launch vehicle expenditure. It is a proven system using existing launch facilities and is a logical candidate for a minimum LTEP mission.

2. Titan IIID/Agena. The Titan IIID is a two-stage Titan III core with two five-segment, 120-inch solids attached. The Transtage is replaced with the Agena, 16,000 lb thrust, upper stage. The Titan IIID/Agena combination has a slight payload advantage over the Titan IIIC; however, the size/volume problem is more complicated with the longer and smaller-diameter (5-foot) Agena vehicle. Growth capability is slightly increased but does not appear to warrant the additional upper stage/LTEP design interface disadvantages. This consideration would be offset if a Large Tank Agena should become available.

3. Titan IIID/LTEP. The Titan IIID (no upper stage) can deliver approximately 26,000 lb to a 100 x 220 nm orbit, the capability is approximately 26,000 lb. A hammerhead adapter to the Core II 120-inch diameter is required. The guidance problem without the Transtage would have to be solved and the Core II cutoff dispersions would be a major problem. In addition, the ascent portion of the mission would be dependent upon utilization of the on-orbit spacecraft propulsion system. These factors precluded further consideration of this approach despite the potential increase in payload capability. If the payload should become extremely marginal this program-unique approach might be re-examined.

Table 21

CAPABILITIES OF CANDIDATE LAUNCH VEHICLES FOR THE LTEP MISSION

Rank No.	Launch Vehicle	Approximate Payload Capability (lb)
1.	Titan IIIC	23,800
2.	Titan IIID/Agena	25,600
3.	Titan IIID/LTEP	26,000
4.	Saturn IB	27,700
5.	Titan IIID/Centaur	33,300
6.	Titan IIIF	36,200
7.	Saturn IB/LTEP	36,200
8.	Titan IIIF/Centaur	45,300
9.	Saturn IB/Centaur	48,300
10.	Interm. 20 (3 F-1)	75,000
11.	Space Shuttle	80,000
12.	Interm. 20 (4 F-1)	126,000
13.	Interm. 21	192,000
14.	Saturn V	242,000
15.	Interm. 21/LTEP	250,000

4. Saturn IB. The Saturn IB is the lowest cost man-rated launch vehicle with the capability of launching either the LTEP module or the manned CSM; it has 1.6 million lb thrust at liftoff. Thus, the same vehicle could be utilized for a dual-launch mission implementation. The diameter of the SIVB stage is compatible with the LTEP module configuration so that no hammerheading is necessary. This proven system would utilize existing KSC facilities. In addition, the NASA launch vehicle stable may provide spare or residual SIB launch vehicle systems within the required time frame (1974-75) depending upon final AAP program utilization for 1972-73 missions. The capability of the SIB to the desired orbit ($\approx$27,700 lb) provides significant growth contingencies for the system without excessive uncommitted weight margins.

5. Titan IIID/Centaur. The Centaur second-stage, powered by two 15,000 lb thrust hydrogen-oxygen engines can be used with a Titan IIID base stage. While this configuration compares well from a performance and cost standpoint, it is not man-rated; thus a different vehicle would have to launch the manned CSM. Also, since the payload increase above the SIB (5,600 lb) is not required to launch the LTEP system, the addition of these stages to a manned LTEP program does not appear warranted.

6. Titan IIIF. The Titan IIIF has two seven-segment, 120-inch solids attached to the core. These provide 2.8 million lb thrust at sea level. The cost and performance of the vehicle compare favorably. It appears, however, that the Titan IIIF will not be developed since the 7-segment solid development (Titan IIIM) was contingent on requirements for the cancelled MOL program.

7. Saturn IB/LTEP. The Saturn IB/LTEP utilizes the Saturn IB to inject the LTEP at perigee of a 100 by 220 nm elliptical transfer orbit. Following separation from the SIVB, the LTEP coasts toward apogee where the LTEP propulsion system circularizes the orbit. If the acceleration level is of the order of 1 ft/sec^2 the burn can be centered about apogee with relatively small losses. For an order of magnitude lower acceleration it may be advantageous to use several revolutions to circularize, raising perigee only a fraction of the distance in a short burn arc over each of several apogee passages. The comments on this approach to launch vehicle implementation contained in the discussion of the Titan IIID/LTEP are essentially applicable to the Saturn IB/LTEP candidate combination.

8. Titan III F/Centaur. The capabilities of the Titan III F/Centaur configuration far exceed the mission requirements for the LTEP module alone considering reasonable growth capability. The capability is not great enough, however, to simultaneously launch the manned CSM, nor is it man-rated.

9. Saturn IB/Centaur. The comments on the Titan III F/Centaur configuration are equally applicable to the Saturn IB/Centaur.

10. Intermediate 20 (3 F-1 engines). The Intermediate 20 is a two-stage derivative of the Saturn V, comprised of a modified SIC (only three F-1 engines) and a slightly modified SIVB. Its capability (75,000 lb) is sufficient to inject the LTEP module and the manned CSM (approximately 60,000 lb total) into orbit in a single launch. This performance, however, is based on a Hohmann transfer type ascent which may not be feasible. The ability of the SIVB J-2 engine to restart with nearly empty propellant tanks, and to shutoff after adding a velocity increment of only 211 ft/sec, is questionable. Also, availability of this vehicle combination requires final development.

11. Space Shuttle. The Space Shuttle with its significant capability and low launch cost is a good candidate, when it becomes available, for the simultaneous LTEP/CSM launch. This experiment would not tax the low-cost-to-orbit features of the contemplated shuttle and could be easily accommodated in the cargo bay of this recoverable vehicle.

12. Intermediate 20 (4 F-1 engines). This 4 F-1 Intermediate 20 vehicle provides considerably more than enough capability for this mission. The short firing at apogee for the assumed Hohmann transfer could be a problem. If direct ascent is used the capability drops to approximately 115,000 lb. This vehicle then is the alternate to the 3 F-1 Intermediate 20 configuration if the Hohmann transfer is a problem with that vehicle. A practical utilization of the excess capability (e.g., Space Station resupply in lieu of the space shuttle) would be required to properly use this vehicle.

13. Intermediate 21. The Intermediate 21 vehicle is another derivative of the Saturn V, consisting of the first two stages. Since the SII does not have a restart capability, the direct ascent mode would be used. The 192,000 lb capability does not appear to be needed to perform the LTEP mission. This vehicle combination, similar to the Intermediate 20 versions of the Saturn family, requires final development implementation.

14. Saturn V. The Saturn V three-stage liquid rocket is the launch vehicle for the Apollo lunar mission and can place 135 tons in low-earth orbit or send a 50-ton spacecraft to the moon. This vehicle is only required if the LTEP orbit is changed to a very high altitude, for example, 24-hour synchronous orbit. It could place the combined LTEP/CSM to this higher altitude.

15. Intermediate 21/LTEP. In order to utilize the full capability of the Intermediate 21, a Hohmann ascent with LTEP propulsion circularizing at apogee is used. This capability, however, far exceeds the requirements for the LTEP mission.

The LTEP and LTEP/CSM postulated weights provide a reference point for comparison of the vehicles. Two altitudes are considered of prime importance, 220 nm and the 24-hour synchronous orbit. Since the first nine launch vehicle combinations considered (through Saturn IB/Centaur) can place the LTEP weight above the lower altitude and the latter six can place the combined LTEP/CSM to this orbit, or the LTEP alone to synchronous orbit, consideration is reduced to selection of a minimum cost vehicle within the appropriate family. The selected vehicles, Titan IIIC and Saturn IB, cost approximately \$17 million and \$33 million, respectively. These are the minimum cost unmanned and man-rated vehicles which can accomplish the LTEP mission without introduction of significant vehicle modifications and/or developments.

Inherent in the Mode 1 (The SWS-II LTEP) configuration and operational implementation is the fact that, as an AAP experiment, the LTEP module will be launched along with other experiments by the Saturn V. The lowest-cost launch vehicle with the performance capability for launching the minimum configuration (Mode 2) with adequate margin for contingency and growth is the Titan IIIC ; therefore it is the preliminary selection for this mode. The Rendezvous LTEP, (Mode 3), having the same configuration as Mode 2 but with a cluster docking operation, would utilize the same launch vehicle, Titan IIIC. The Saturn IB is the initial selection for the heavier Mode 4 (i. e., Independent/Manned LTEP) since it has payload capability with adequate margin to be consistent with the conceptual level of configuration definition existing at this time. The SIVB diameter is also compatible with the LTEP module diameter avoiding the hammerhead which would be required by other launch vehicles in the same class. The Saturn IB is also the only man-rated vehicle in this class so that, in a dual-launch mode, it would boost the CSM. Therefore, its selection to also boost the LTEP module will simplify the integration of the mission and avoid introducing another set of vehicle personnel. The Saturn IB is also the alternate selection for Modes 2 and 3. The Intermediate 20 is an alternate possibility for Mode 4 since it possesses the capability for launching the LTEP module and the manned CSM in a single launch. Its development is not complete, however, and use of this approach would be contingent on NASA accomplishment of the vehicle integration.

Orbit mechanics parameters for the 220 nm, 35 deg inclined orbit, including sun angle variations, sun occultation time and Earth shadowing effects, are summarized in Appendix B.

5.2 LTEP THERMAL ANALYSIS

An analysis was conducted on the 2-meter LTEP telescope configuration to determine the performance of the thermal control system; a multitude of missions were considered to determine the design environments. Considering the thermal environments and the current LTEP mission, the temperature gradients across the primary mirror are less than 1^oC and the mirror operating temperature levels range from a high of -71^oC to a low of -84^oC for the 220 nm low earth orbit. (Synchronous earth orbit operation results in lower temperature levels which are desirable; this alternate orbit, therefore, was not analyzed in detail.)

5.2.1 Mission Environment

The LTEP mission environment depends upon the configuration, operational mode, and orbit altitude. The LTEP can be utilized in the AAP Cluster-docked mode with the dry orbital workshop (DWS) or hard-docked to the space station. The LTEP can operate detached from both the AAP Cluster and space station. The LTEP configuration for the AAP Cluster can be unmanned, or manned; these configurations also apply to the space station application. Also, the LTEP can be used by itself in the independent or autonomous modes in both the manned or unmanned configurations which presents identical thermal environments to the LTEP as for the detached modes. Thus, the configurations considered for thermal analysis purposes were:

a. LTEP docked to the AAP cluster: DWS – Docked Operation (Mode 1 and Mode 3 – docked)

b. LTEP hard docked to the space station: Space Station – Hard Docked Operation (Mode 1A – docked)

c. LTEP detached from AAP cluster: LTEP – Detached Operation (Modes 1 and 3 – detached)

d. LTEP detached from space station: Space Station – Detached Module Operation (Mode 1A – detached)

e. LTEP independent or autonomous: Unmanned Application (Mode 2) – This configuration is the same thermally as c.

f. LTEP independent or autonomous: Manned Application (Mode 4) – This configuration is the same thermally as d.

Several orbit altitudes were considered; (a) 20,000 nm synchronous earth orbit, (b) 250 nm low earth orbit and (c) 220 nm low earth orbit. The Beta (β) angles (acute angle between the orbit plane and the earth sun line) considered ranged from 0 deg to ±52.5 deg for the synchronous and 250 nm altitudes and from 0 deg to ±60 deg for the 220 nm altitude.

The LTEP was considered to be space oriented and the angle between the center line of the telescope and sun was either 0 deg or 45 deg for low β angles and either 45 deg or 90 deg for all high β angles. When the LTEP is operating, 250 watts of power is dissipated in the rack for the support subsystems. These conditions represent the maximum and minimum environments for the LTEP.

5.2.2 Design Requirement

The temperature gradients across the primary mirror must be less than $1^{o}C$ in order to achieve the desired optical performance. The desired operating temperature level of the telescope primary mirror is $-80^{o}C$.

5.2.3 Thermal Control System Design

The thermal control system design for the LTEP is achieved by the use of a very low solar absorptance (α_s)/infrared emittance (ϵ) ratio surface, the use of multilayer insulation, internal optical black coating and a sun shield cap. The low α_s/ϵ ratio surface is the Optical Solar Reflector (OSR) with an α of 0.05 and an ϵ of 0.80. The low α_s/ϵ surface is used to achieve the low primary mirror temperature; the multilayer insulation is used to minimize the orbital temperature fluctuations; the optical black coating equalizes the internal temperatures, and the sun shield cap is used to prevent impingement of direct solar energy on the primary mirror.

OSR is the lowest α_s/ϵ ratio surface of all the currently used thermal control materials which is flight proven. The OSR is basically a second-surface mirror composed of silver deposited on high-purity fused silica. The material is extremely stable in the in the space environment. Results of laboratory simulated exposures to Van Allen proton, artificial electron belt, solar wind proton, solar ultraviolet, and selected combinations of environments have demonstrated virtually no degradation. (Reference 7-12).

High performance multilayer insulation, consisting of alternate layers of double-aluminized mylar (1/4-mil thick) and tissuglas spacers (0.6 mil thick), is used to insulate the telescope. The insulation blanket layer density is 100 mylar layers per inch, with alternate layers of tissuglas, resulting in a density of 2.3 lb per cu ft. The internal walls of the telescope are covered with a 1/2-inch blanket of multilayer insulation as well as the interface between the telescope and the equipment rack. The internal surface of the insulation is coated with a highly diffuse optically black paint to equalize the internal temperatures.

The effective thermal conductivity of the multilayer insulation varies as a function of the boundary temperatures. The effective conductivity as a function of the number of layers and boundary temperatures has been determined under NAS 8-20758 ("Investigations Regarding Development of a High Performance Insulation System"). The expression for the effective thermal conductivity is:

$$k_{eff} = F \left[1.83 \times 10^{-12} (M)^2 T_m + \frac{1.7\sigma \left(T_H^2 + T_c^2\right)\left(T_H + T_c\right) t}{(N-1)(2/\epsilon - 1)} \right]$$

where:

k_{eff} = effective conductivity, Btu/hr ft^{o}R

$$T_m = \frac{T_H + T_c}{2}$$

N = actual number of layers used

T_H = hot boundary temperature, ^{o}R

T_c = cold boundary temperature, ^{o}R

t = insulation blanket thickness, ft

ϵ = emittance of the radiation shield = 0.036

σ = Stefan Boltzmann constant

F = 5 (installation degradation factor)

The effective thermal conductivity expression was programmed and used during the thermal analysis of the LTEP. To prevent incident solar energy striking the mirror surface, a movable sun shield cap located at the forward end of the telescope closes. Any incident solar energy on the mirror would raise its operating temperature level.

Scale model (1/6.43) thermal vacuum tests of the 2-meter telescope have substantiated the effectiveness of the thermal control system design (Reference 7-13). The multi-layer insulation provides an effective adiabatic wall and damps out the fluctuating external surface temperatures. The test results have also verified the analytical predictions of primary mirror temperature gradients within $1^{o}C$.

5.2.4 Thermal Analysis

The thermal mathematical model of the two-meter telescope system developed for the Optical Technology Experiment Study (OTES), Reference 7-11, has been updated to the LTEP configuration. The surface optical properties (α and ϵ), as well as the operational heat dissipation rates, are presented in Table 22 for both the AAP Cluster and the LTEP.

Initial thermal studies were performed for the four thermally different configurations: A) DWS – Docked operation, B) Space Station – Hard Docked Operation, C) LTEP – Detached Operation or Unmanned Application, and D) Space Station – Detached Module Operation or Manned Application. Configurations A and B results were thermally equivalent and configurations C and D were also equivalent. Furthermore there was only a $3^{o}C$ difference in the mirror temperature between the Docked (A and B) and the undocked (C and D) configurations. The mirror temperature level decreases $3^{o}C$ for high β angles from the docked to the undocked configuration. Whereas, the mirror temperature level increases $3^{o}C$ for low β angles from the docked to the undocked configuration. The effect of the AAP cluster or the Space Station upon the LTEP environment results from (a) blockage of both incident heating and radiation to space, (b) radiation heat exchange, and (c) reflection of heat rates. For the high β angles, where the total environment is warmer than for the low β angles, the undocked LTEP configuration results in lower temperatures due to the increased radiation to space and the reduction of reflected heat rates. For the lower β angles an increase in temperatures results due to less blockage of the incident heating which is more significant than the other effects.

Table 22

SURFACE OPTICAL PROPERTIES AND HEAT DISSIPATION RATES

	Solar Absorptance (α)	Emittance (ϵ)	Operating Mode Heat Dissipation (watts)
• Cluster Description			
S-IV-B	0.9	0.9	*
Spacecraft LM adapter (SLA)	0.9	0.9	–
Airlock module (AM)	0.9	0.9	*
Multiple docking adapter (MDA)	0.9	0.9	*
Command and service module (CSM)	0.9	0.9	*
LM/A	0.2	0.5	*
Solar Panels cell side	0.7	0.9	–
Solar panels backside	0.9	0.9	–
ATM rack equipment and panels	0.2	0.9	–
Control moment gyros (3)	0.9	0.9	75
• LTEP Description			
Telescope exterior	0.05	0.80	–
Telescope interior Multilayer insulation	0.9	0.9	–
Figure sensor Support structures	0.9	0.9	–
Secondary mirror Support structure	0.9	0.9	–
Quartz rods	–	0.9	–
Plate support – backing	0.2	0.9	–
Gimbal ring ATM	0.2	0.9	–
Electro-optical Equipment sections	0.3	0.5	175
Primary mirror segments	–	0.05	–

*Modules have internal 50° F. sink.

While the LTEP is operating, 250 watts of power is being dissipated in the support equipment on the rack. The mirror temperature level increases 12.5°C with the power for high β angles and increases 5.7°C with power for the low β angles.

Table 23 presents a summary of the configurations, the thermally equivalent configurations, the effect of docked or undocked configuration on the mirror temperature, and the effect of power in the mirror temperature level. Examination of Table 23 shows that each configuration need not be analyzed for a complete mission spectrum; thus, an undocked independent (autonomous) mode was analyzed in detail. The analysis was conducted for the extreme environment to obtain the maximum mirror temperatures.

Subsequent to the initial analyses, the LTEP mission orbit altitude was defined to be a low earth orbit at 220 nm with a β angle range of 0 deg to 60 deg. The low β angle and telescope aligned with the sun represent the LTEP minimum environment; thus, $\beta = 0^{\circ}$ with 0 deg between the telescope centerline and the sun was analyzed in detail. The high β angles and telescope normal to the sun results in the maximum LTEP environment; thus $\beta = 60$ deg with 90 deg between the telescope centerline and the sun was analyzed in detail.

Figures 68 (a) through 68 (k) present the results of the detailed thermal analysis of the LTEP for the minimum environment of $\beta = 0$ deg, power on, 0 deg between the telescope centerline and the sun, and the autonomous mode. Figures 69 (a) through 69 (k) present the results of the detailed thermal analysis of the LTEP for the maximum environment of $\beta = 60$ deg, power on, 90 deg between the telescope centerline and the sun, and the autonomous mode. The primary mirror temperature level is -84°C (Figs. 68 (a) and (b) for the minimum environment and -71°C (Fig. 69 (a) and (b) for the maximum environment; the gradient across the mirror is less than 1°C.

The operating temperatures of other LTEP components of interest are the secondary mirror, figure sensor, the quartz rods and the electro-optical equipment bays. The minimum environment ($\beta = 0$ deg) and maximum environment ($\beta = 60$ deg) LTEP component operating temperatures are:

Component	Temperature (°C) $\beta = 0$ deg	Temperature (°C) $\beta = 60$ deg
Secondary mirror	-99	-90
Figure sensor	-114	-107
Quartz rods	-96 to -99	-87 to -90
Electro-optical bays	-37 to -43	+2 to -7

The effectiveness of the thermal control system is dramatically illustrated in Figs. 68(k) and 69 (k) where the external surfaces are changing over a wide band and the mirror temperature essentially remains constant. The primary mirror remains constant at -83.5°C for the $\beta = 0$ deg condition while the external insulation surface varies from -62°C to -93°C. For the $\beta = 60$ deg orbit, the primary mirror temperature remains at -71°C while the external insulation surface varies from -50°C to -90°C.

Table 23

CONFIGURATION MIRROR TEMPERATURE LEVELS

Configuration		High β's	Low β's	Power On High β's	Power On Low β's
A. DWS – Docked Operation	Thermally equivalent to B	$3^{o}C$ Warmer		$12.5^{o}C$ Warmer	$5.7^{o}C$ Warmer
B. Space Station Hard Docked Operation	Thermally equivalent to A				
C. LTEP – Detached Operation	Thermally equivalent to D		$3^{o}C$ Colder	$12.5^{o}C$ Warmer	$5.7^{o}C$ Warmer
D. Space Station Detached Module Operation	Thermally equivalent to C				
E. Unmanned Application	Thermally identical to C				
F. Manned Application	Thermally identical to D				

Recent test data on the OSR surface shows an incidence angle dependence of the solar absorptance, α_s. The α_s remains constant for angles of incidence out to 40 deg, then gradually increases at higher incidence angles to an $\alpha_s = 0.07$. In order to assess the effect of the higher α_s, an $\alpha_s = 0.07$ for the OSR surfaces on the LTEP was analyzed. The mirror temperature level increased 1.5°C due to the increased α_s. Because of the high time constant of the telescope system, however, and the relatively small surface area which would experience any increase in the solar absorptance, the actual mirror temperature level increase due to the angular dependence of α_s for OSR would be negligible.

An analysis was conducted to determine the effect of one mirror segment surface finish degrading from an emittance of 0.05 to 0.80. The resultant mirror temperature gradient increased from below 1°C to 10°C. The feasibility of one segment degrading to such an extreme seems remote.

The feasibility of a "cryogenic" telescope which requires a mirror operating temperature level near -200°C was considered. With the passive thermal control design of OSR and multilayer insulation, the minimum mirror temperature level is -89°C for low earth orbits and no power and -96°C for synchronous altitudes. With presently developed low α/ϵ thermal control surfaces (OSR $\alpha/\epsilon = 0.05/0.80$), passive thermal control to attain mirror temperature levels near -200°C while minimizing the gradient to within 1°C is not feasible. A thermal control system to achieve -200°C mirror temperatures will require the use of cryogenic cooling (liquid, refrigerator, etc.). Such an active system would, or course, be necessarily complex and life-limited.

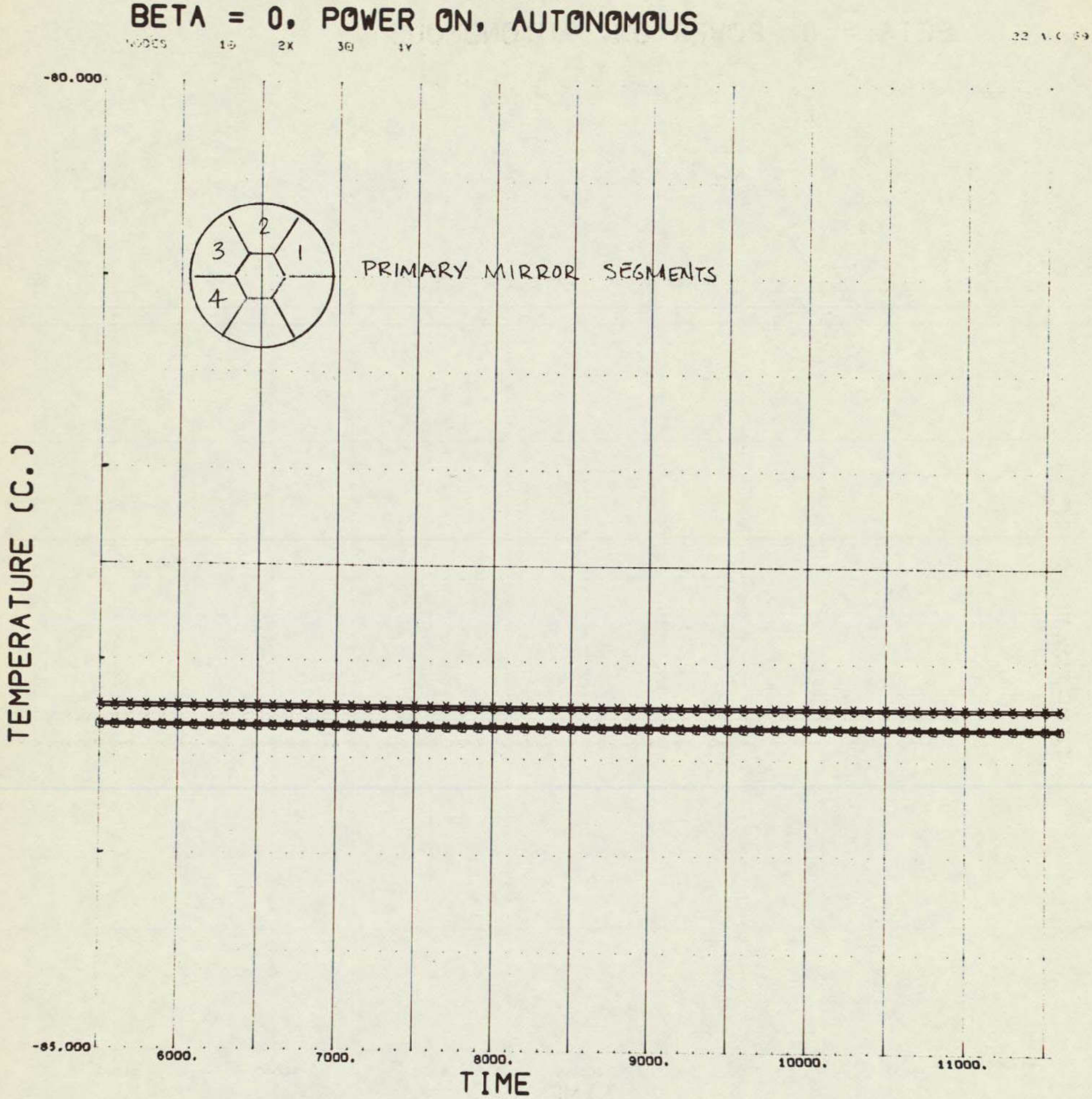

Fig. 68 (a) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-A)

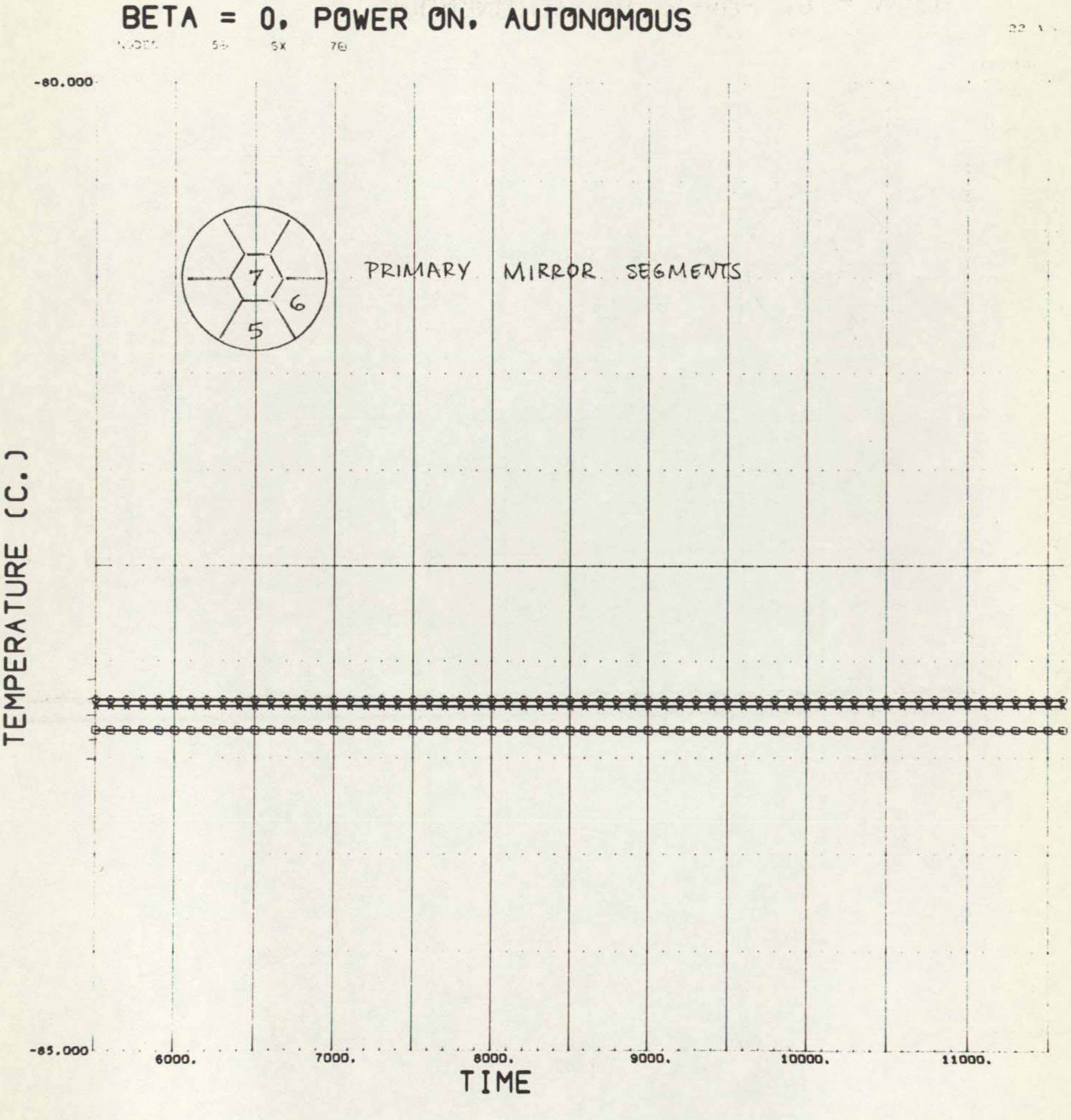

Fig. 68 (b) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-B)

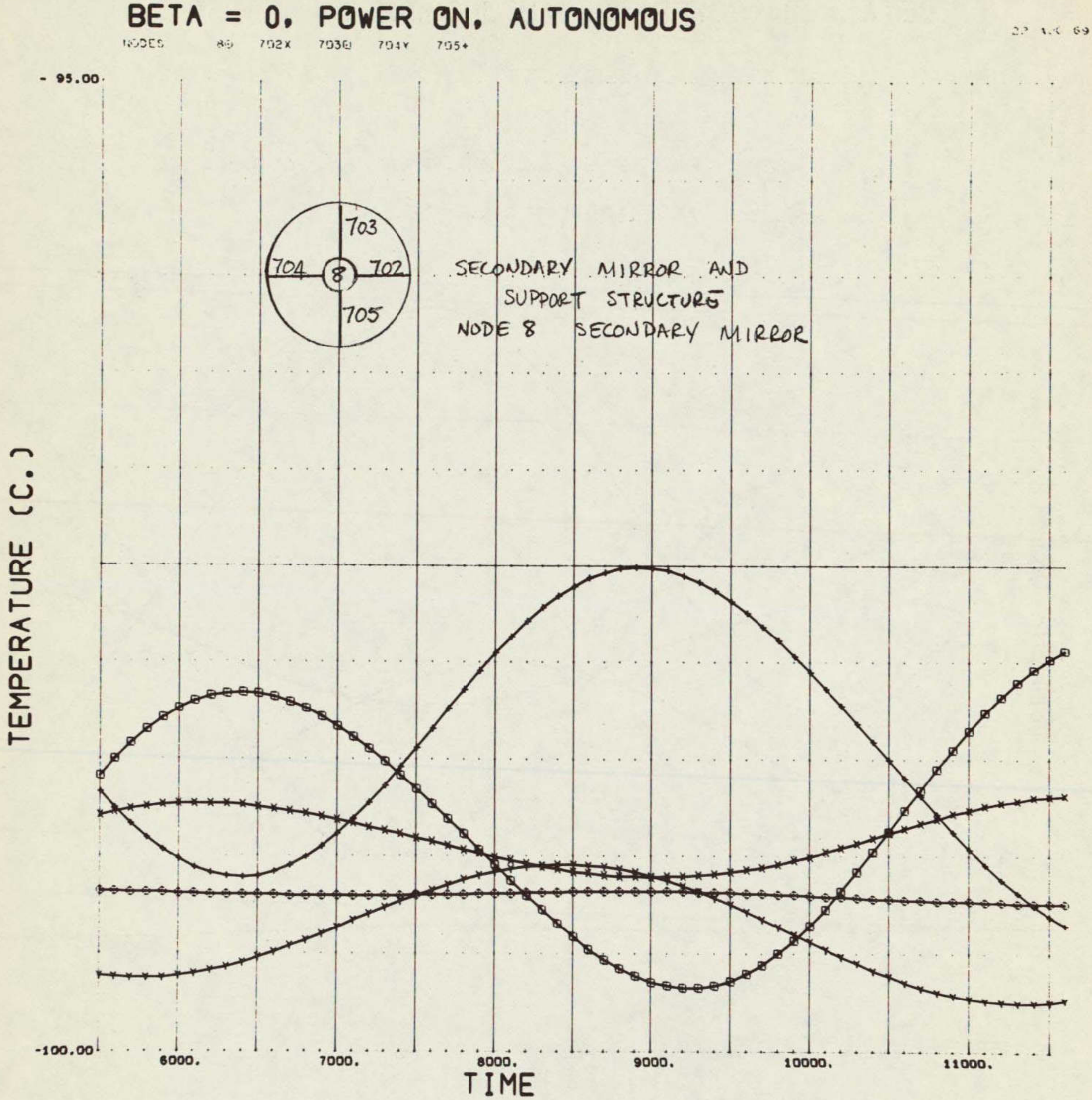

Fig. 68 (c) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-C)

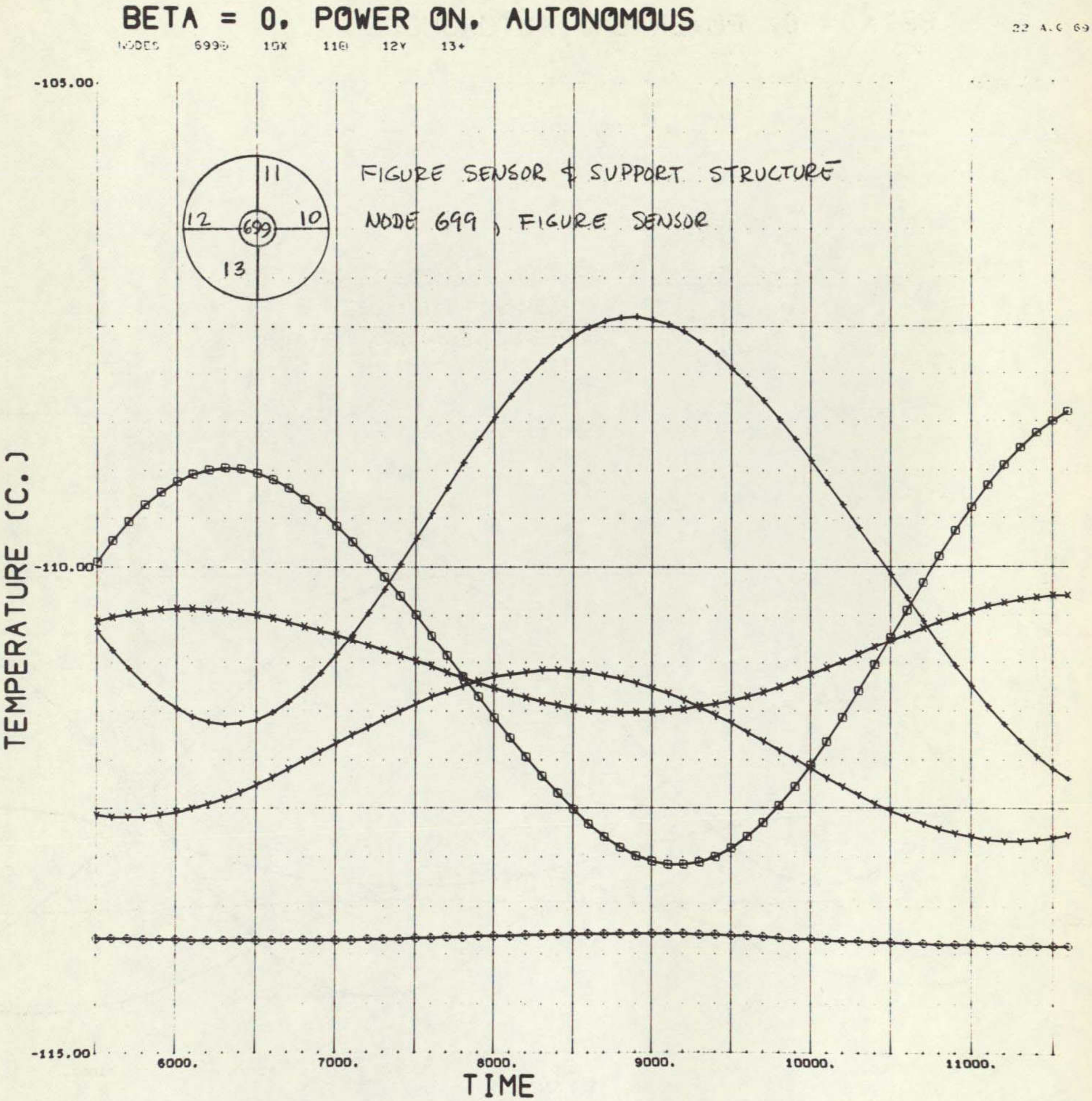

Fig. 68 (d) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-D)

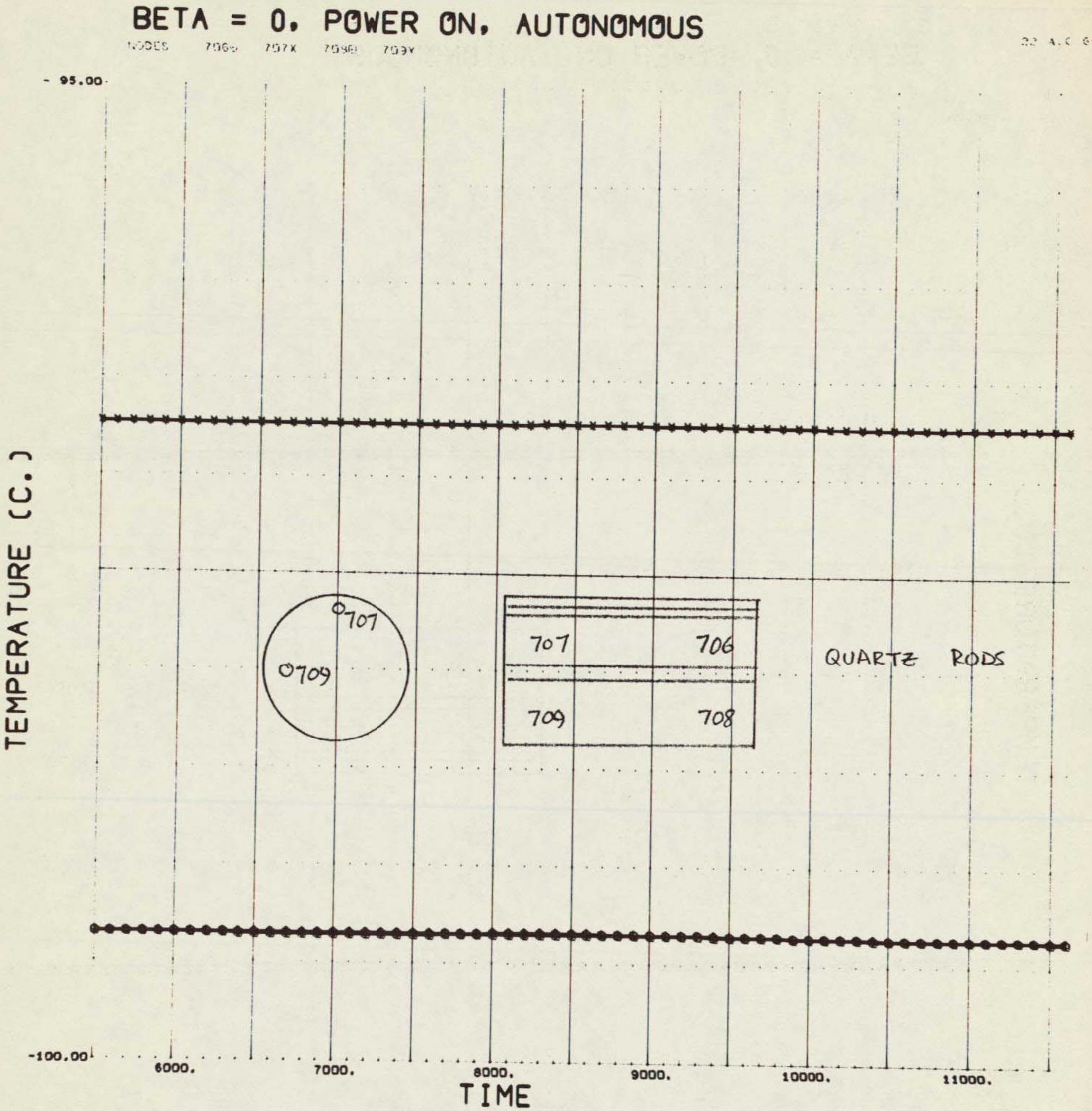

Fig. 68 (e) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-E)

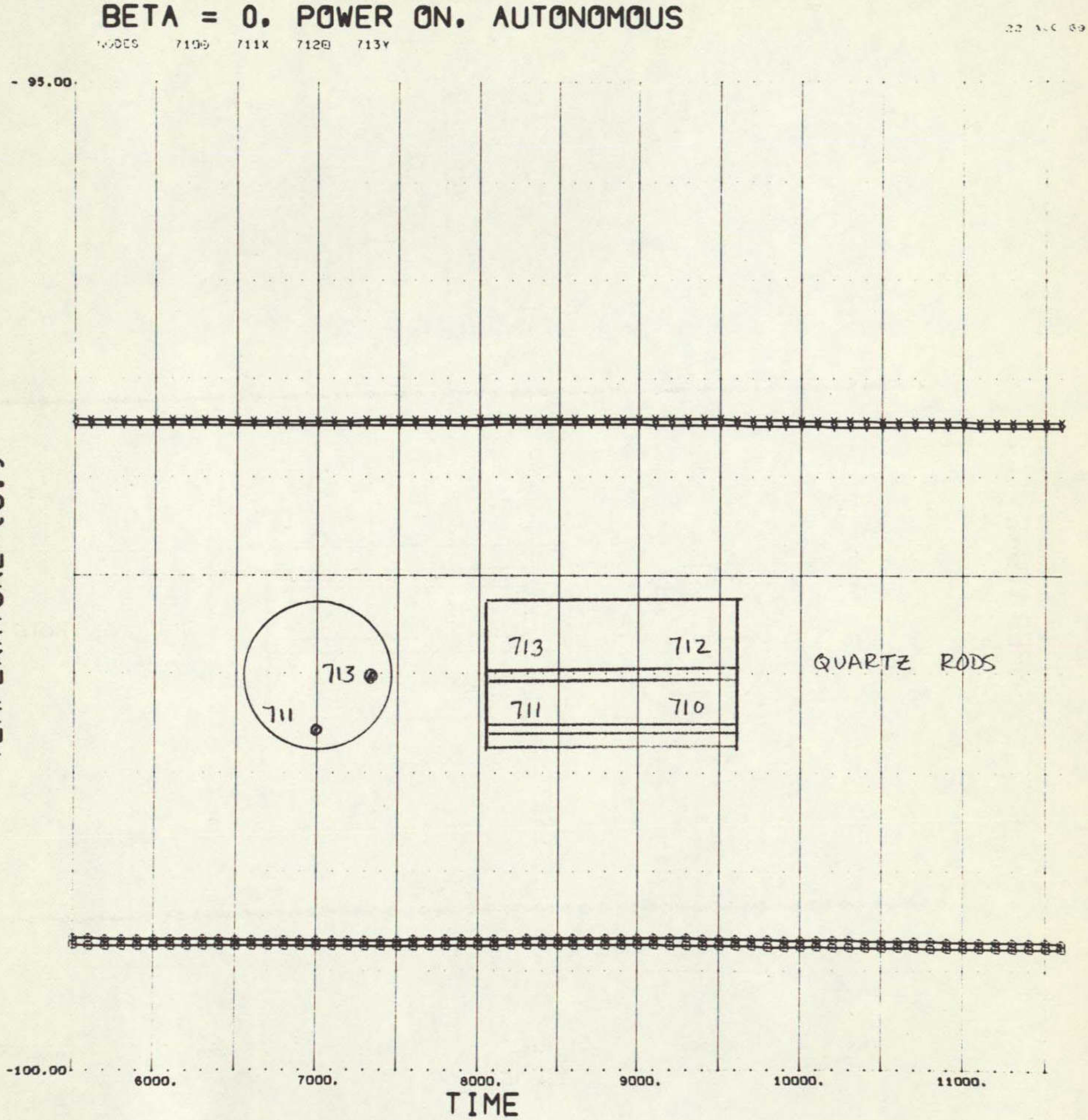

Fig. 68 (f) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-F)

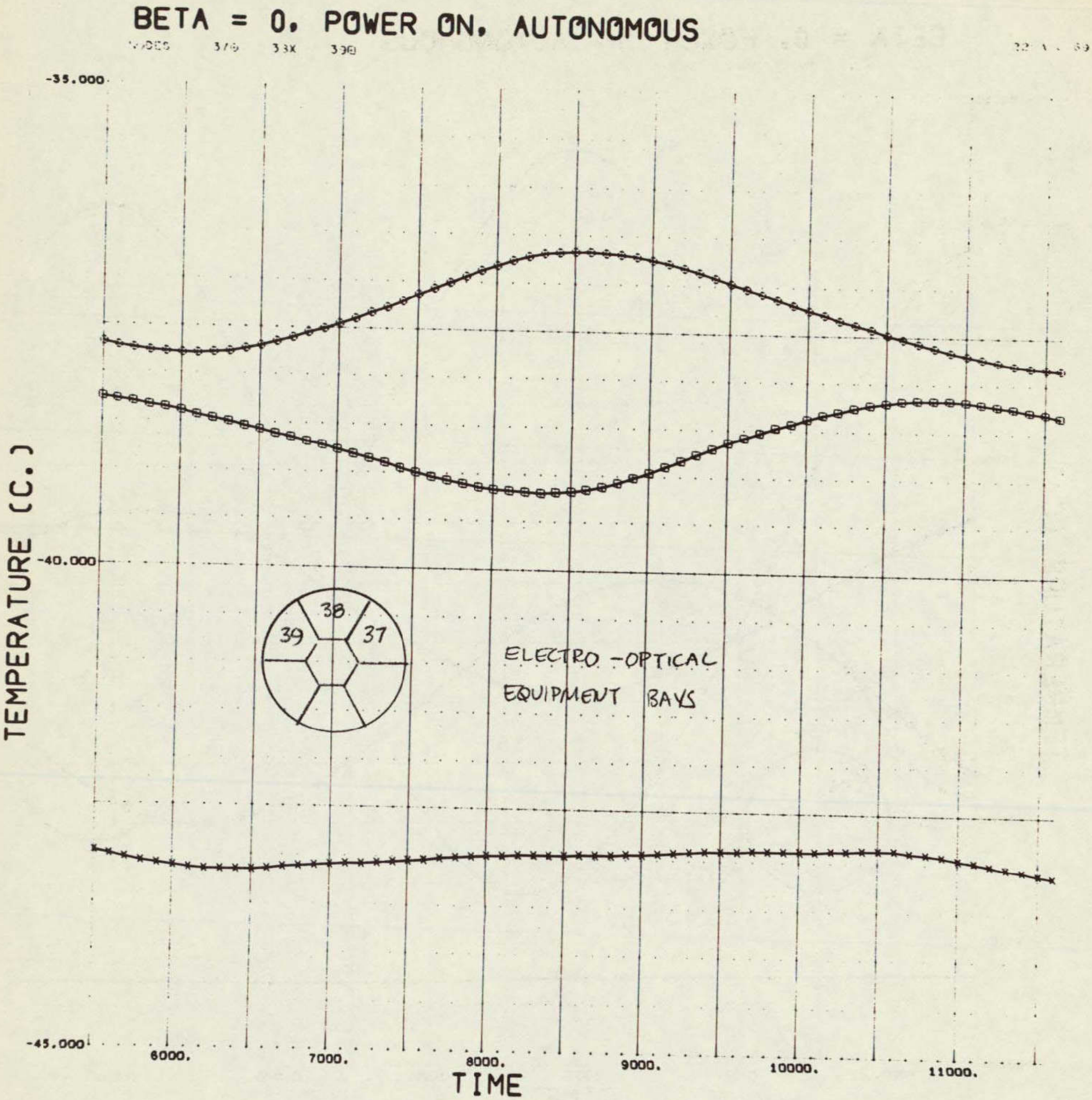

Fig. 68 (g) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-G)

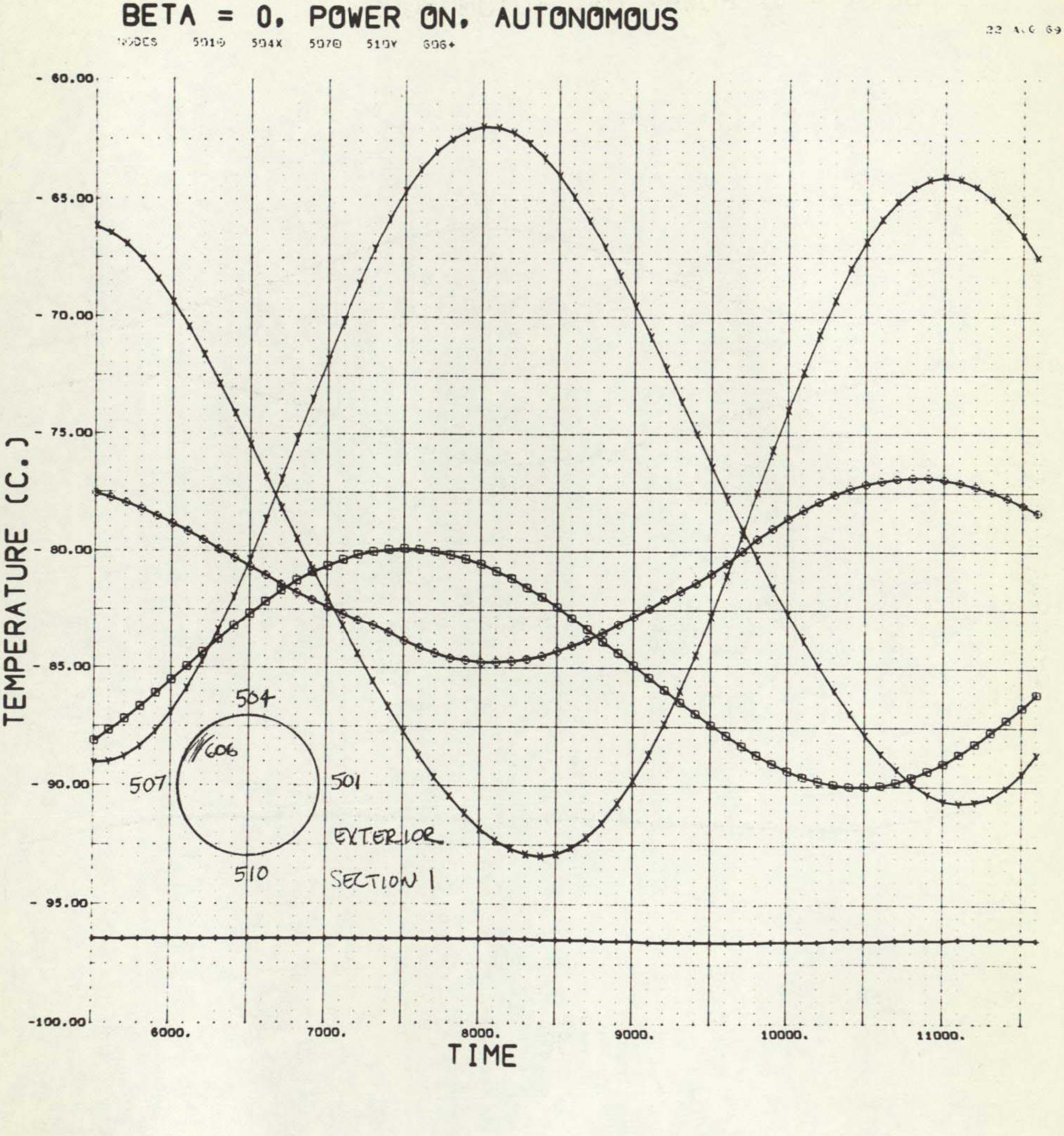

Fig. 68 (h) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-H)

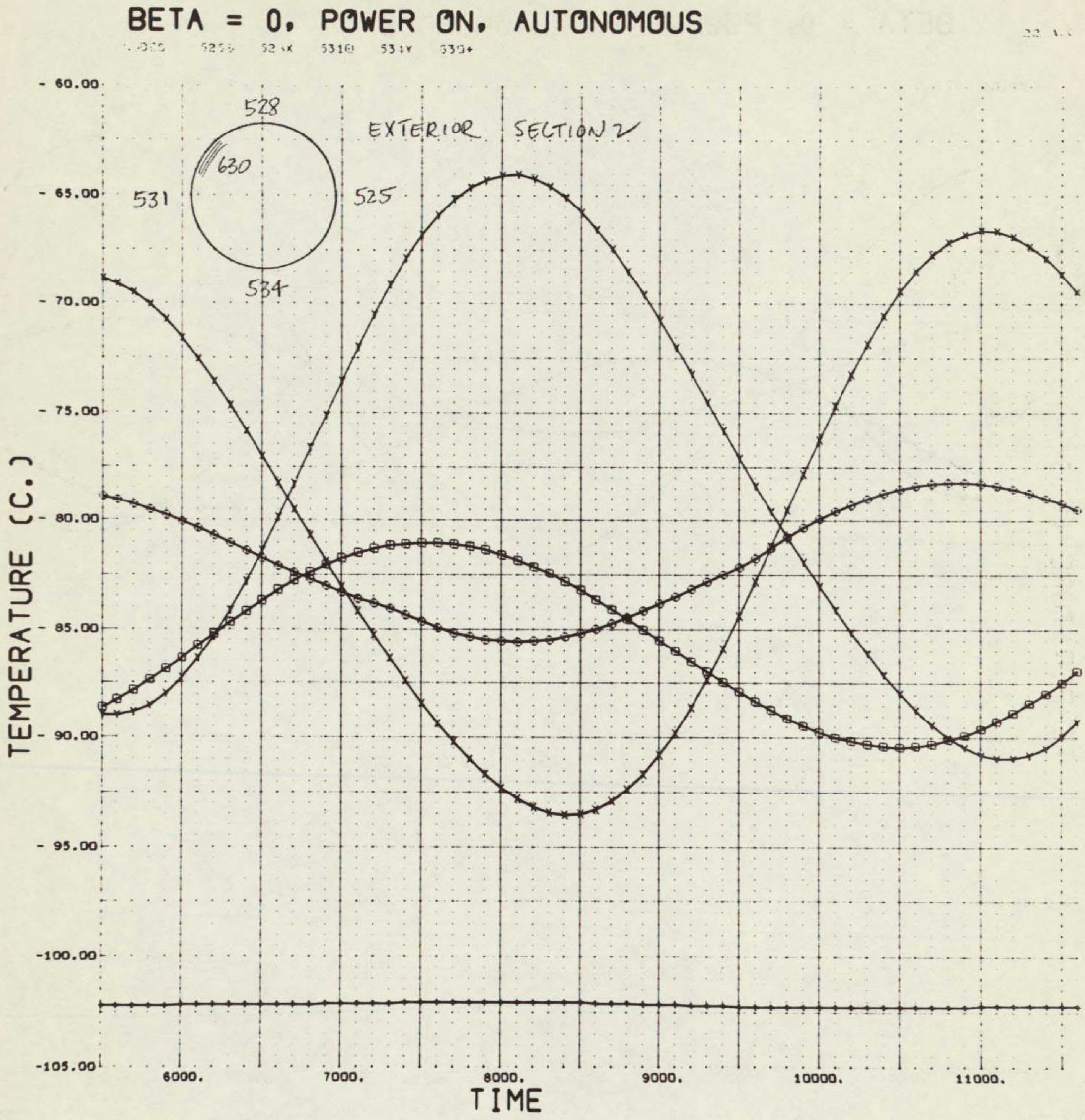

Fig. 68 (i) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-I)

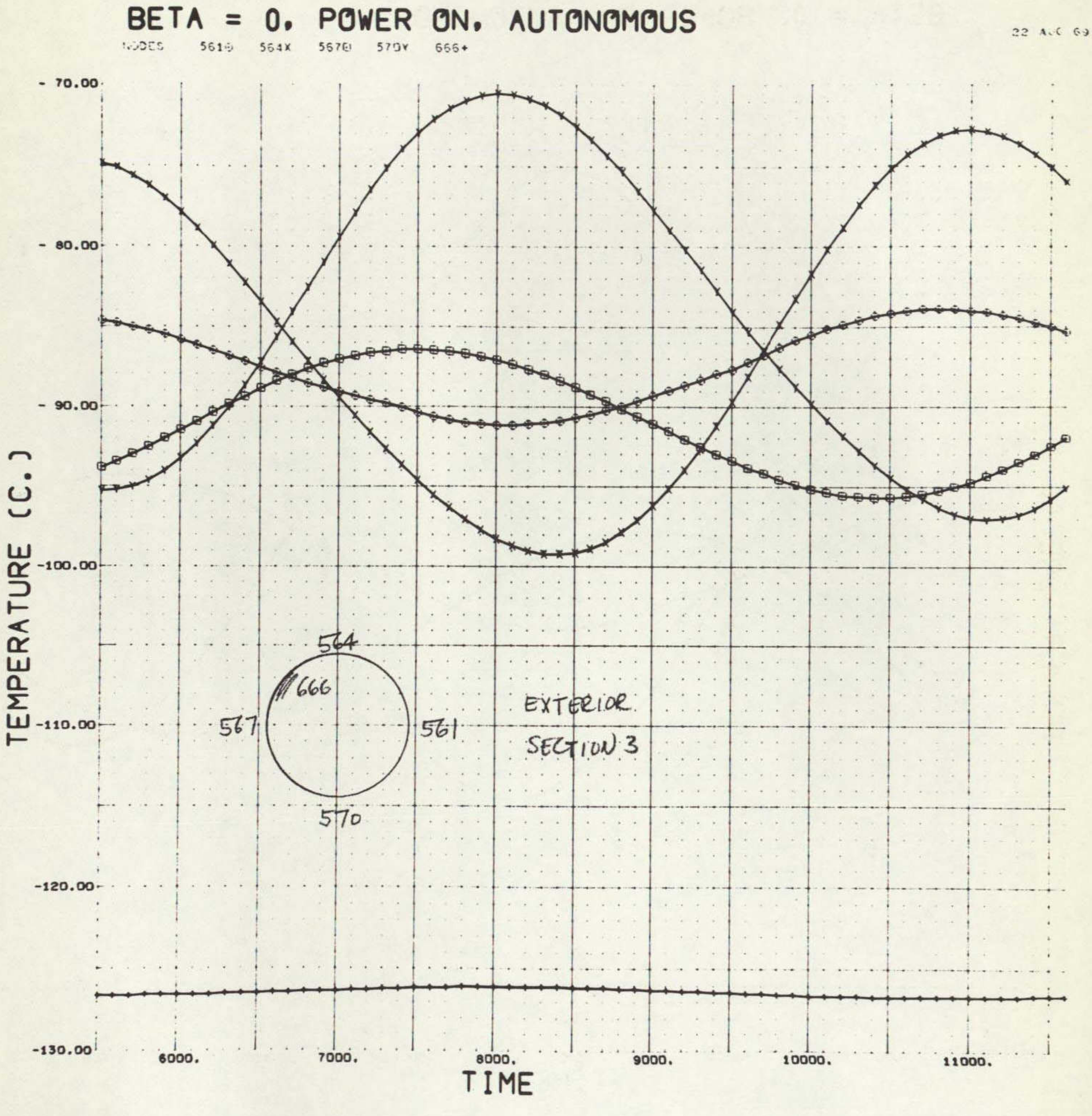

Fig. 68 (j) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-J)

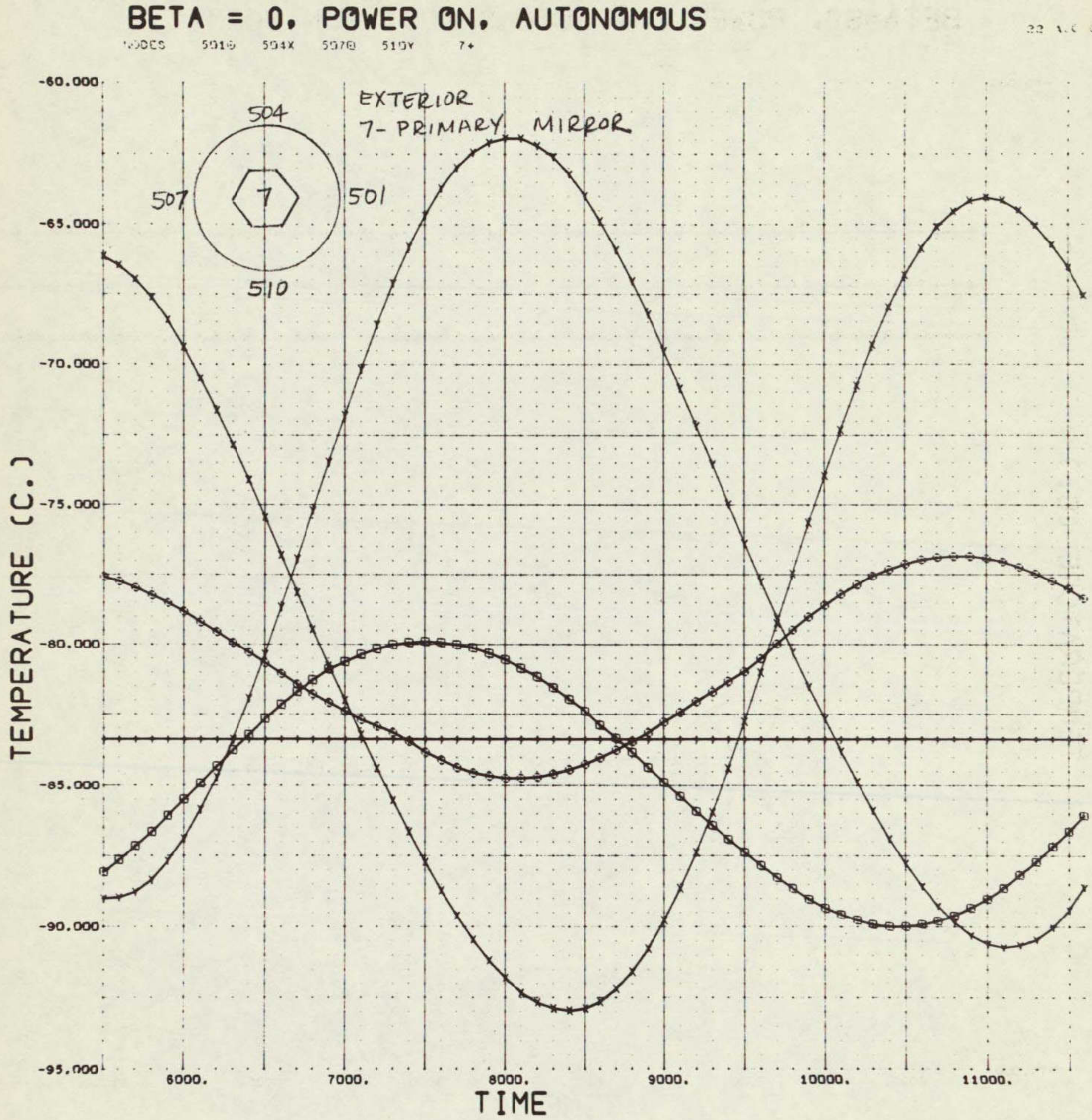

Fig. 68 (k) LTEP Thermal Performance (Beta = 0, Power On, Autonomous-K)

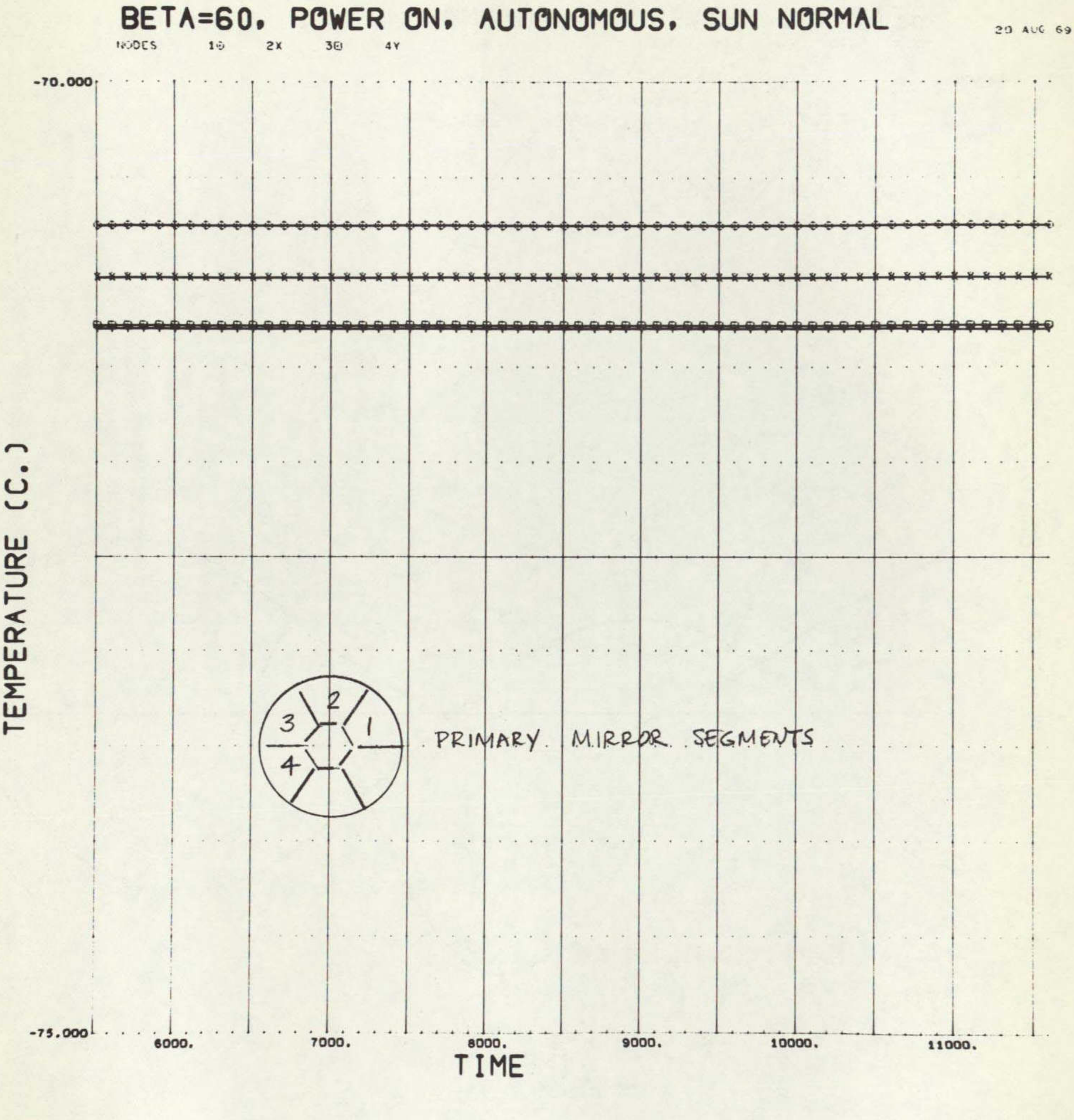

Fig. 69 (a) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-A)

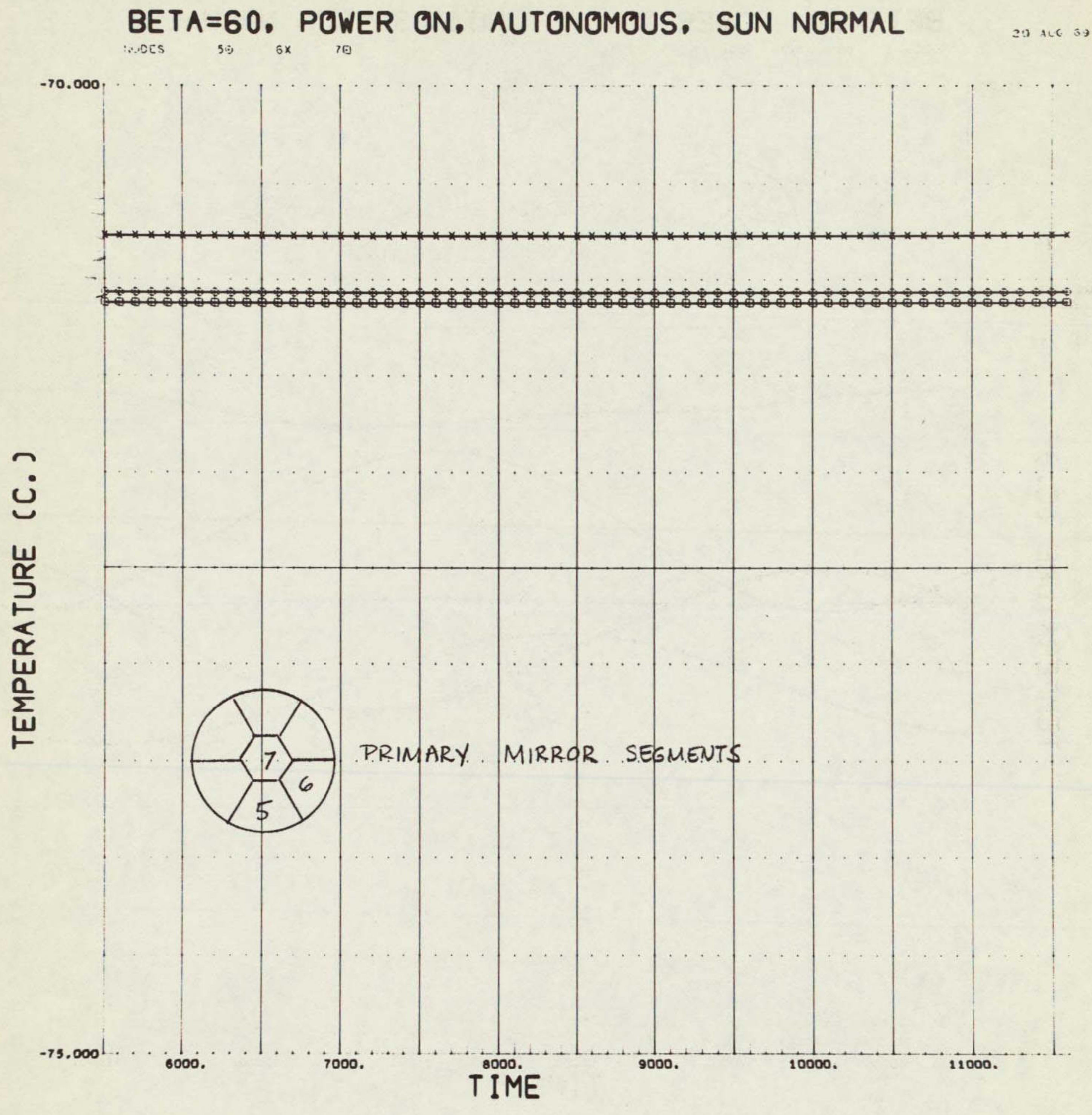

Fig. 69 (b) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-B)

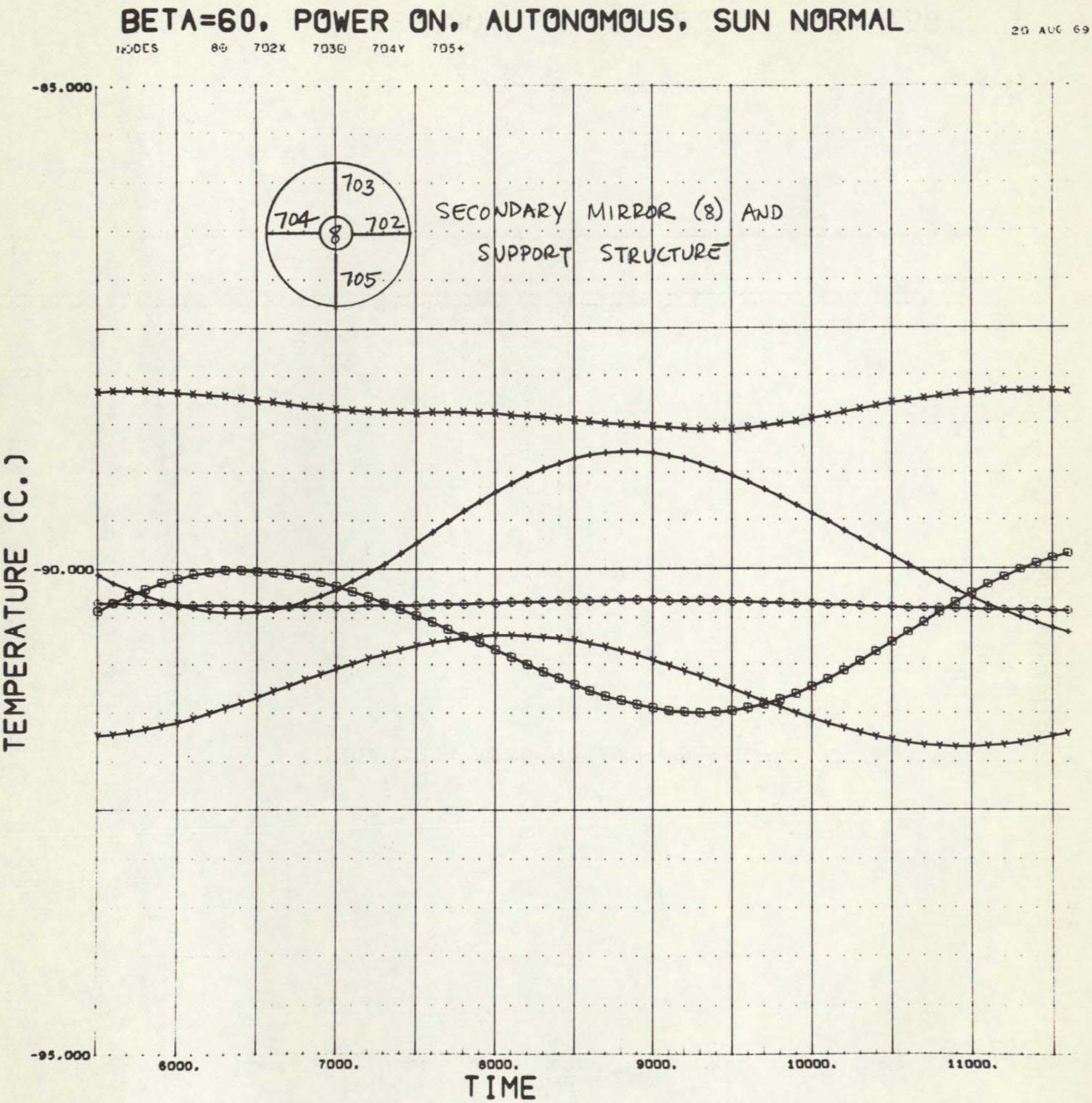

Fig. 69 (c) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-C)

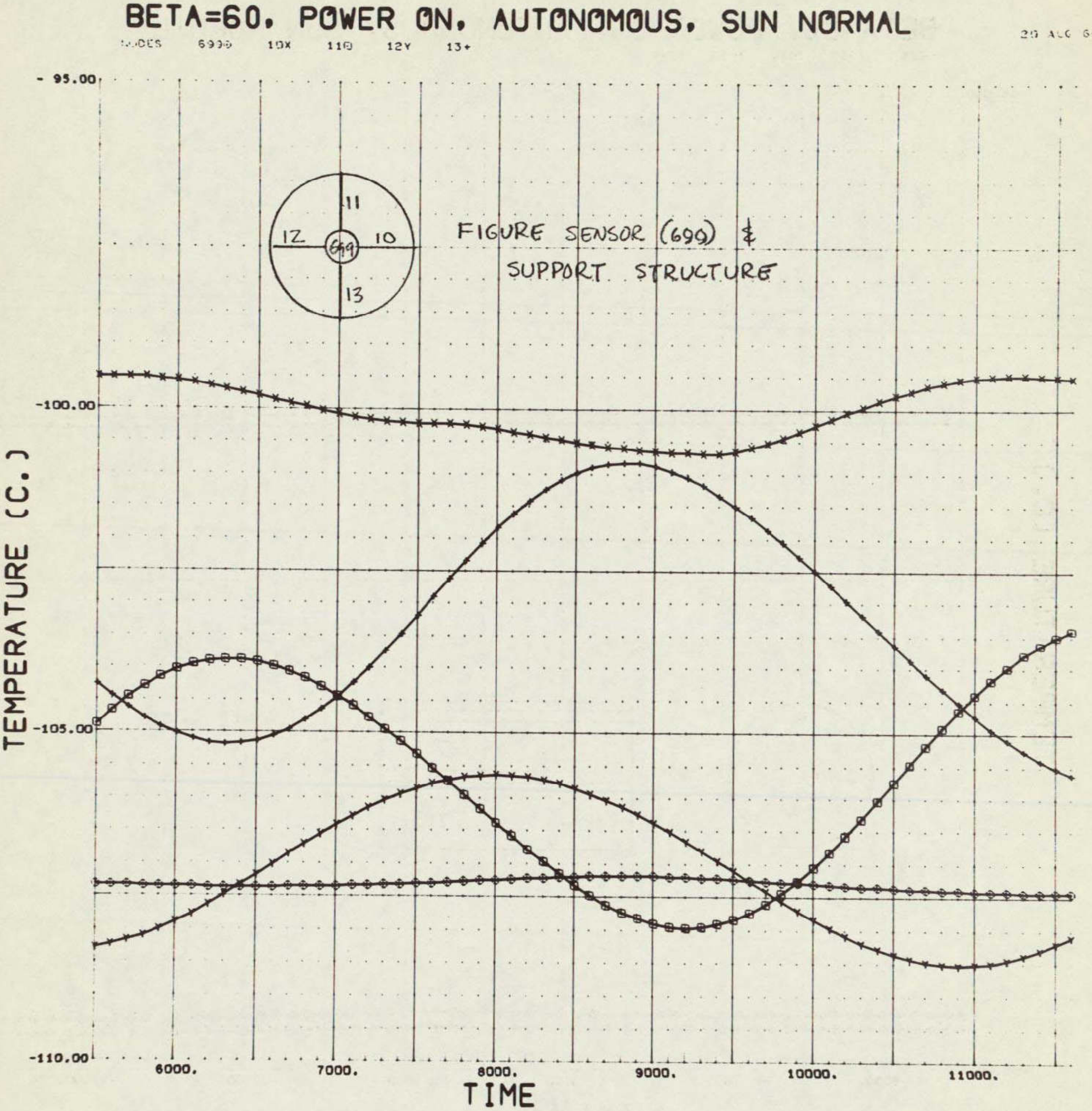

Fig. 69 (d) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-D)

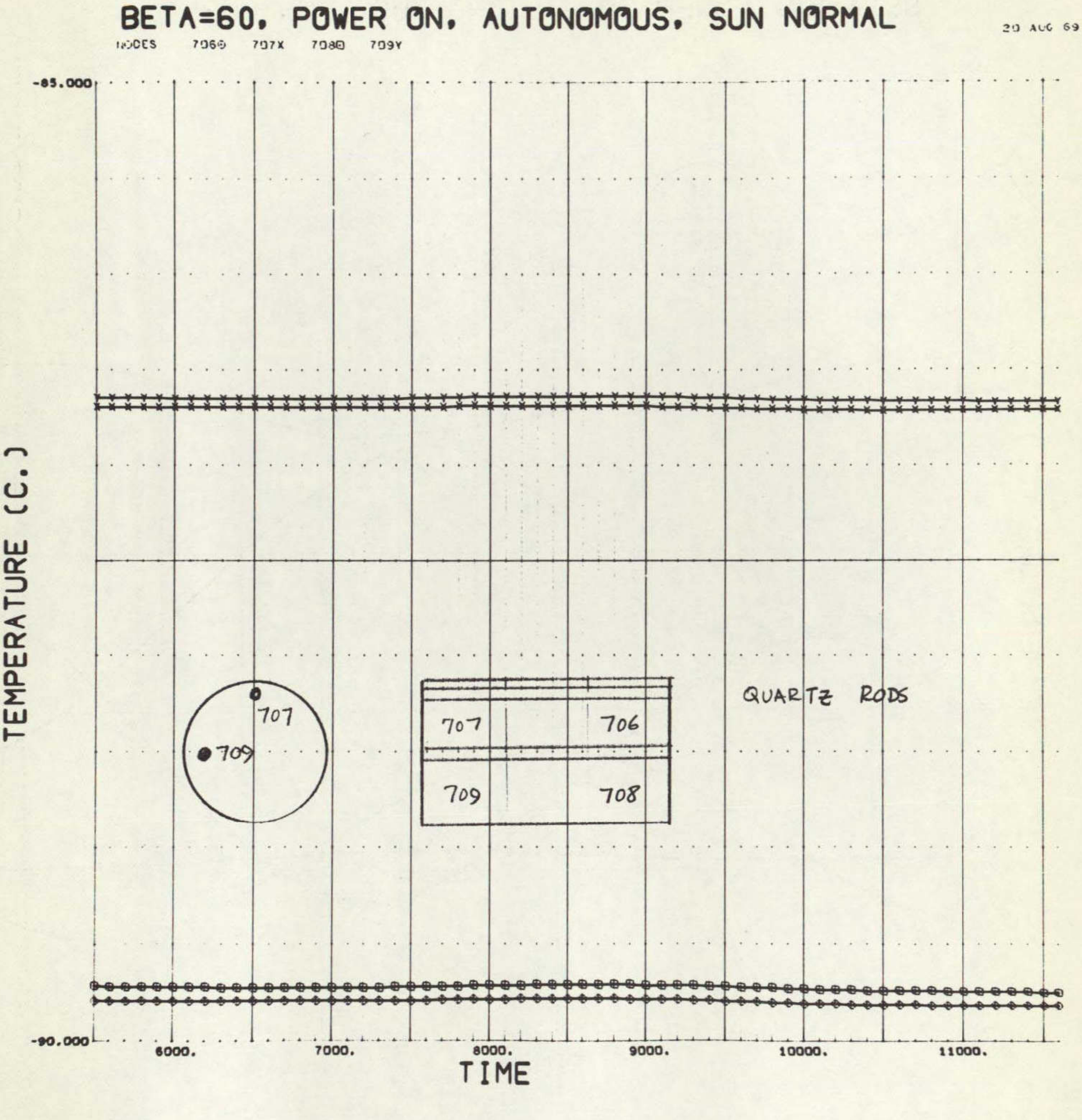

Fig. 69 (e) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-E)

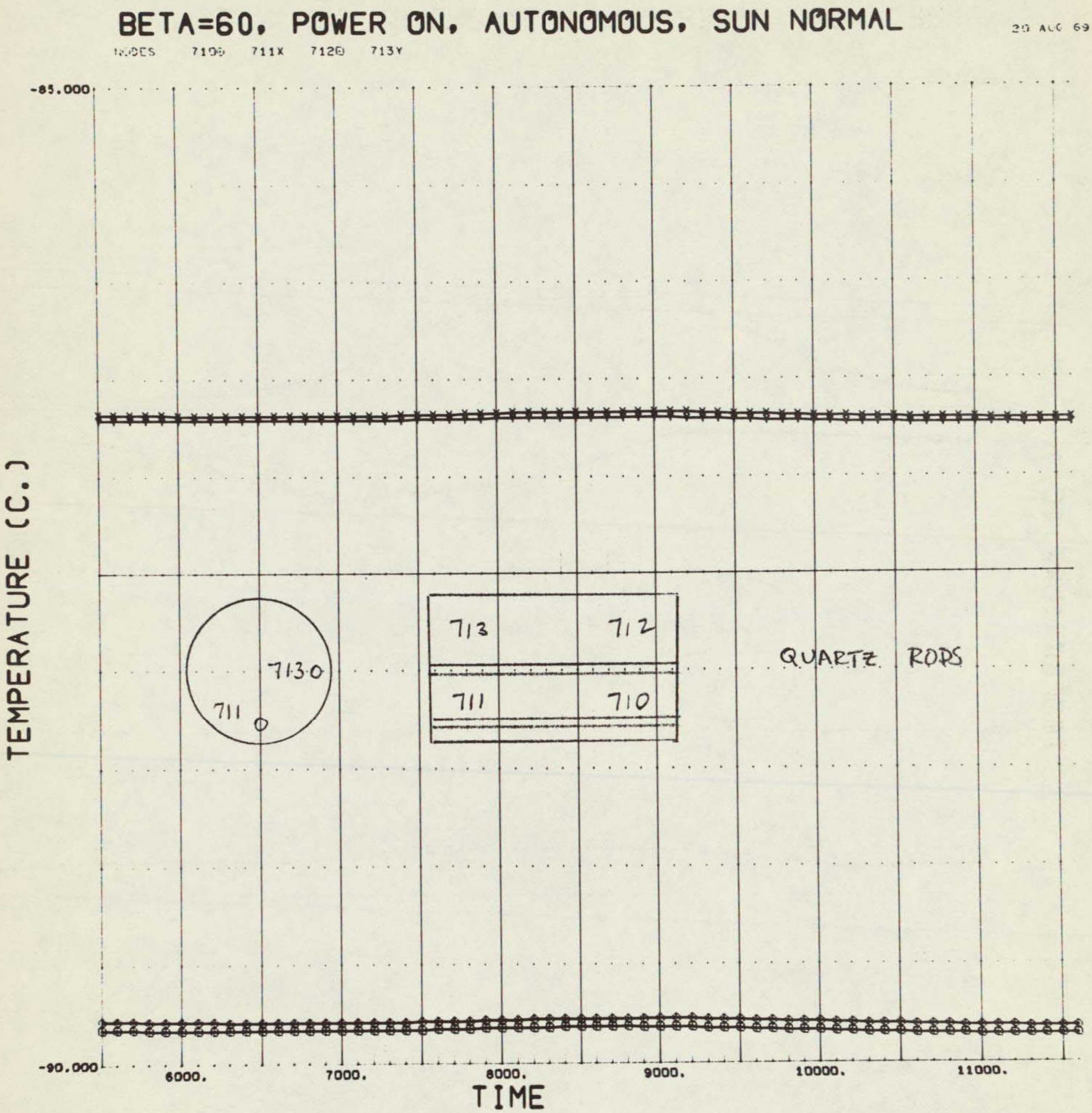

Fig. 69 (f) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-F)

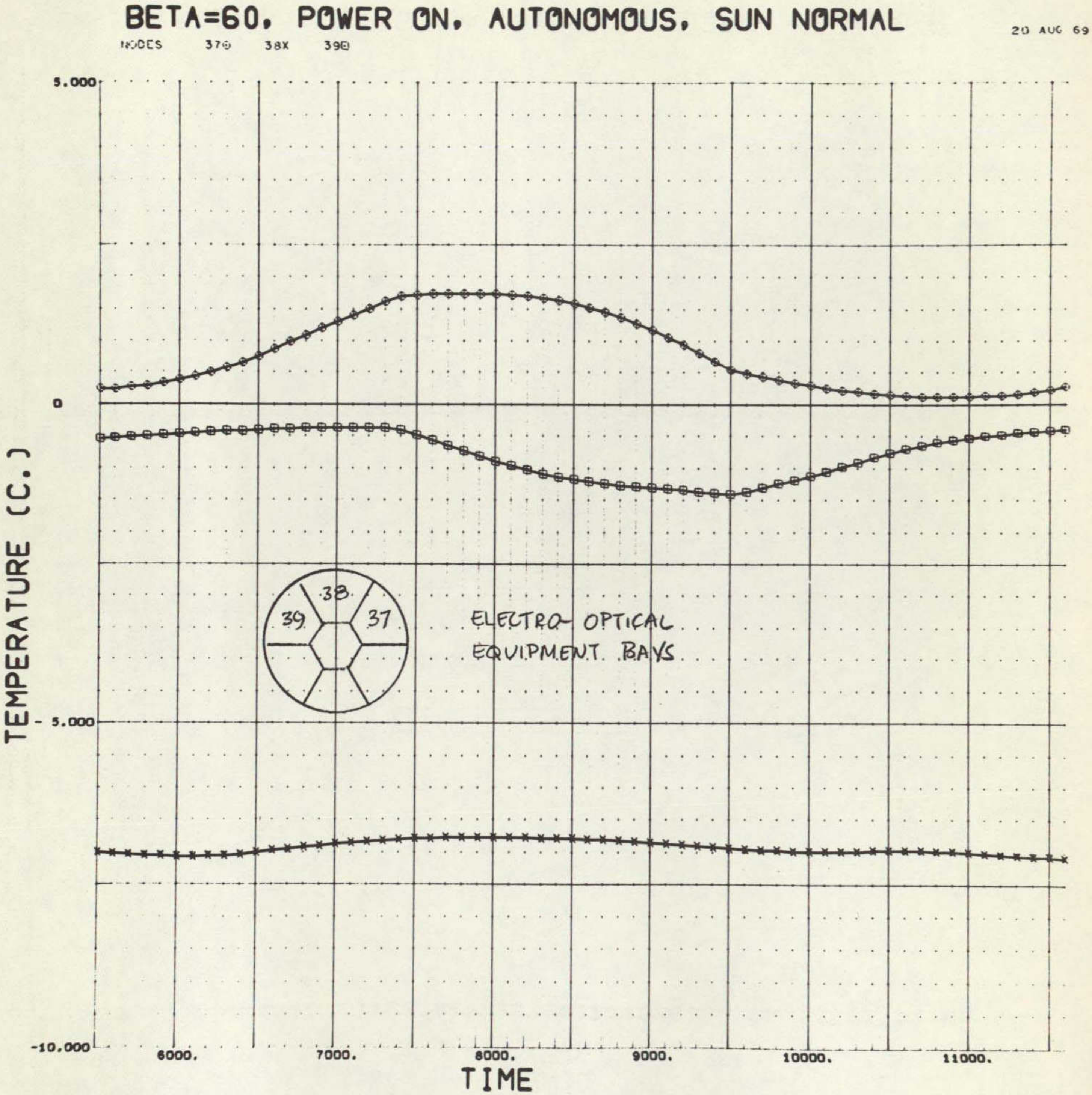

Fig. 69 (g) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-G)

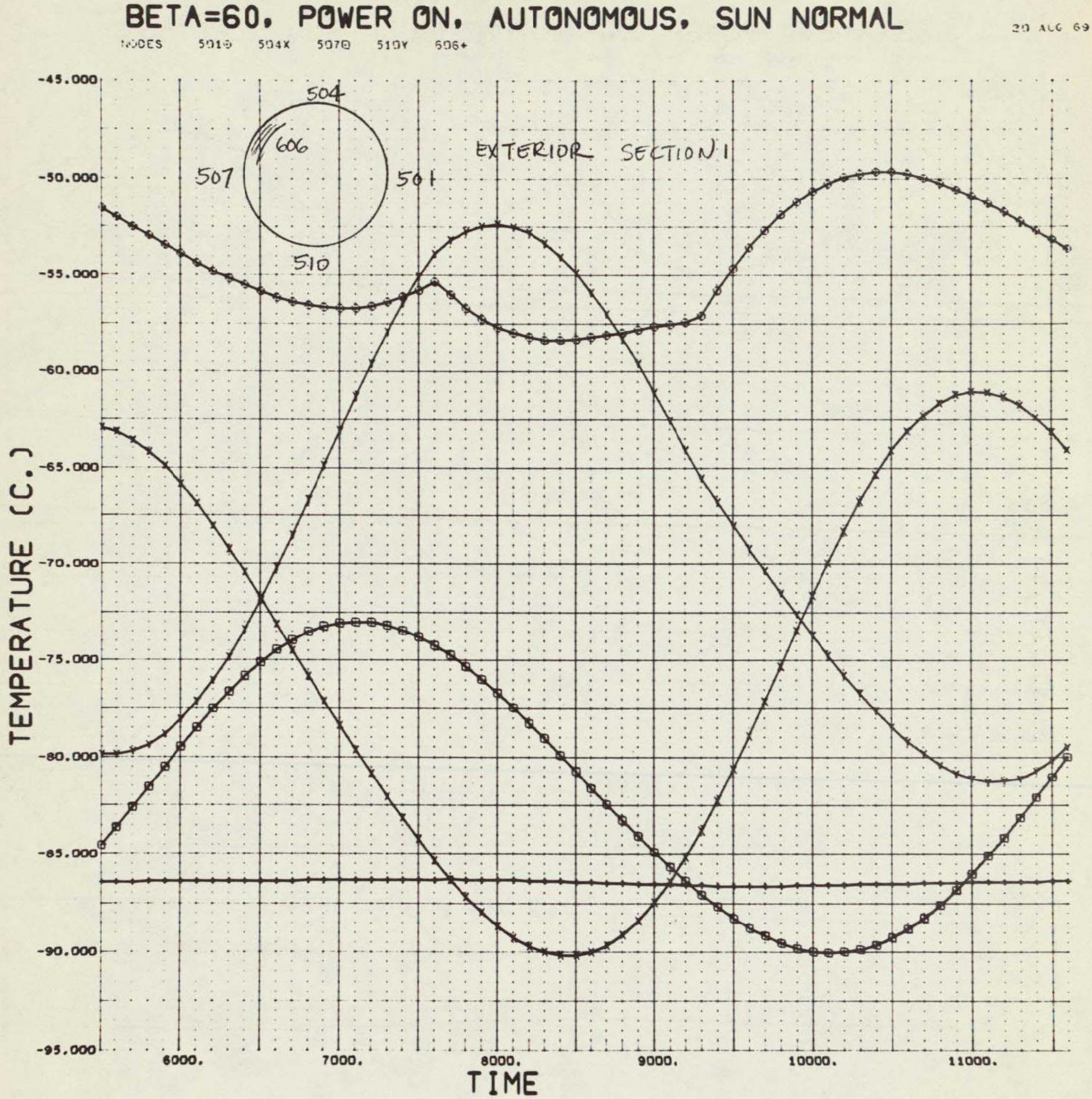

Fig. 69 (h) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-H)

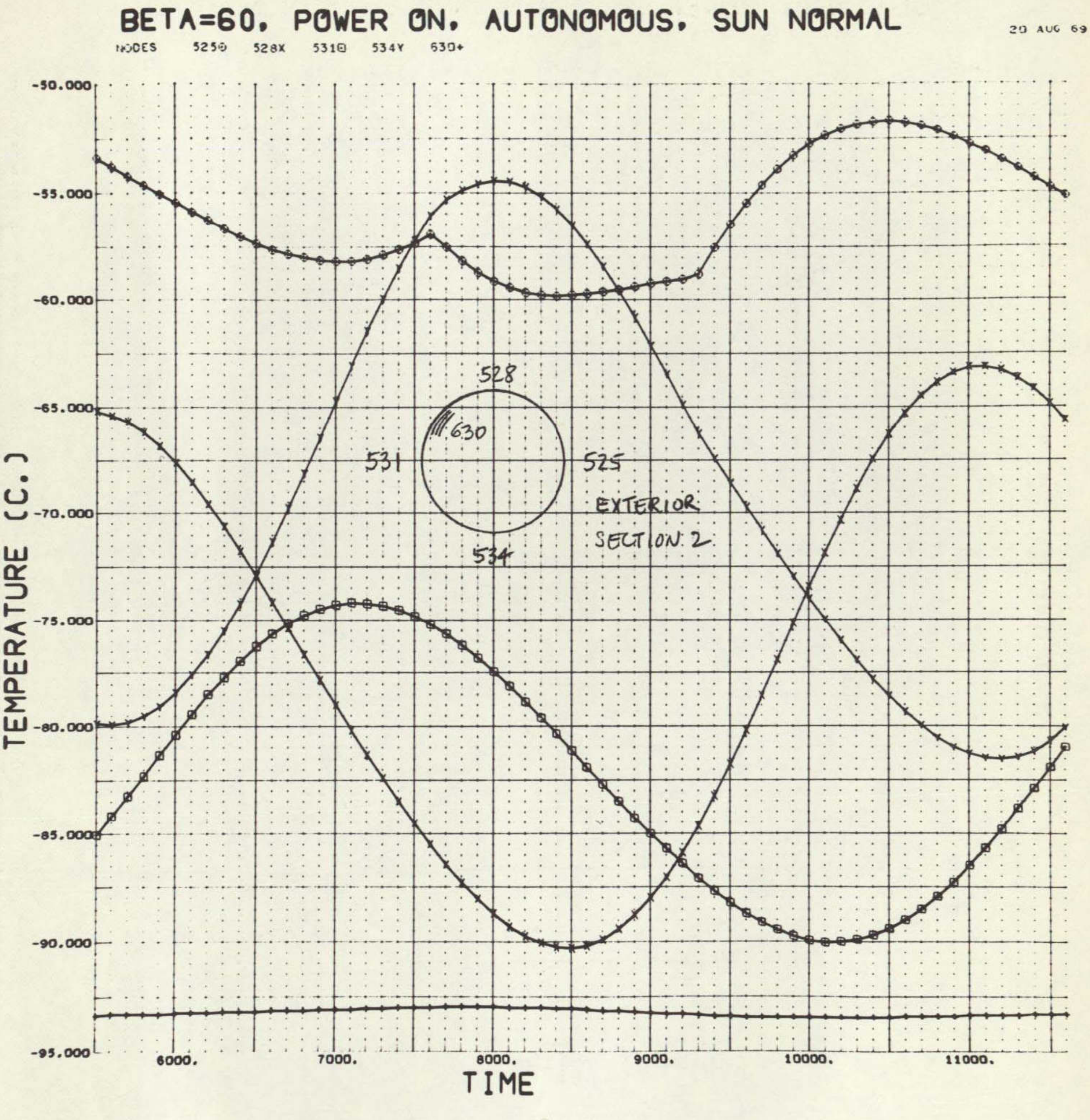

Fig. 69 (i) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-I)

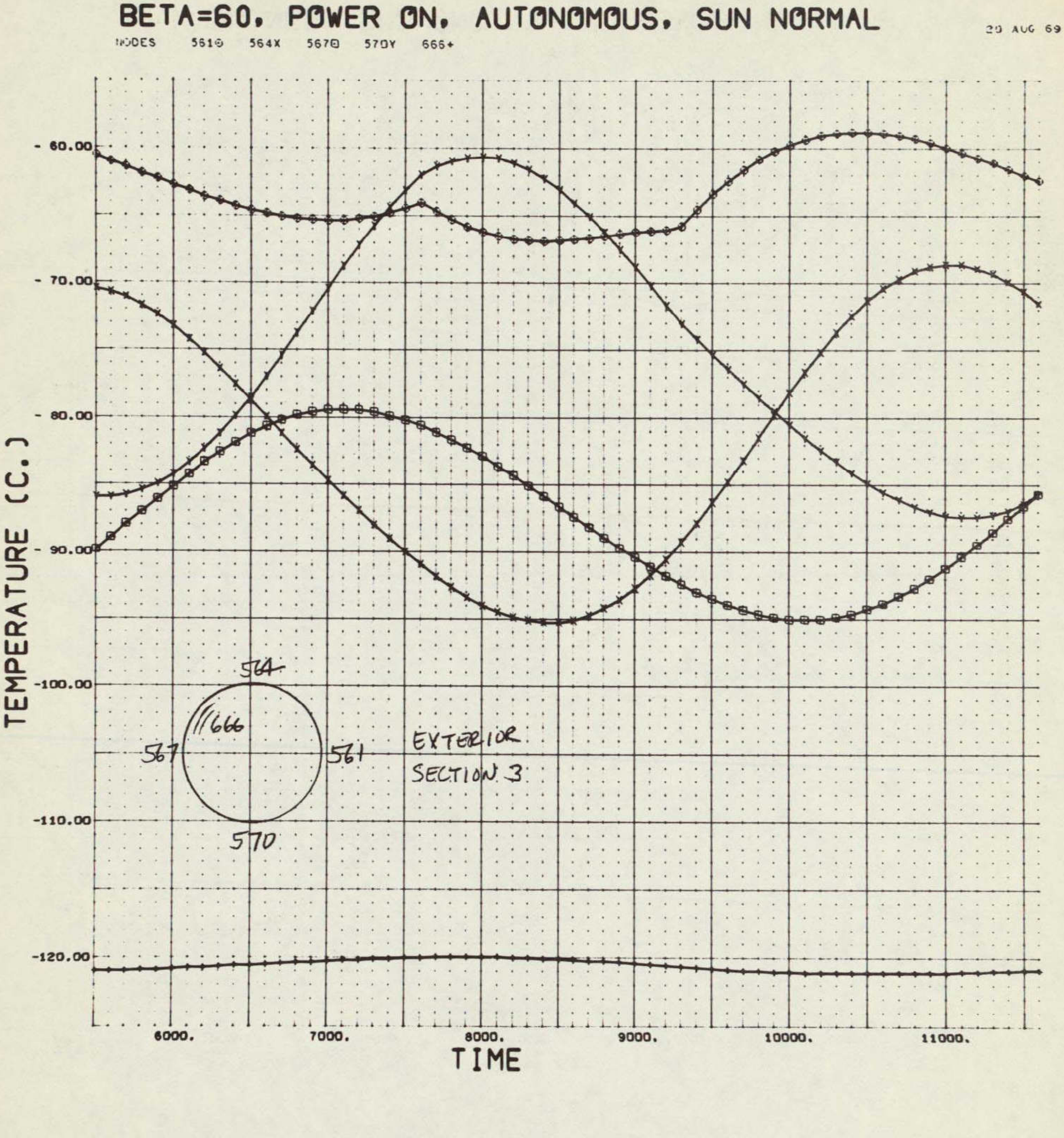

Fig. 69 (j) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-J)

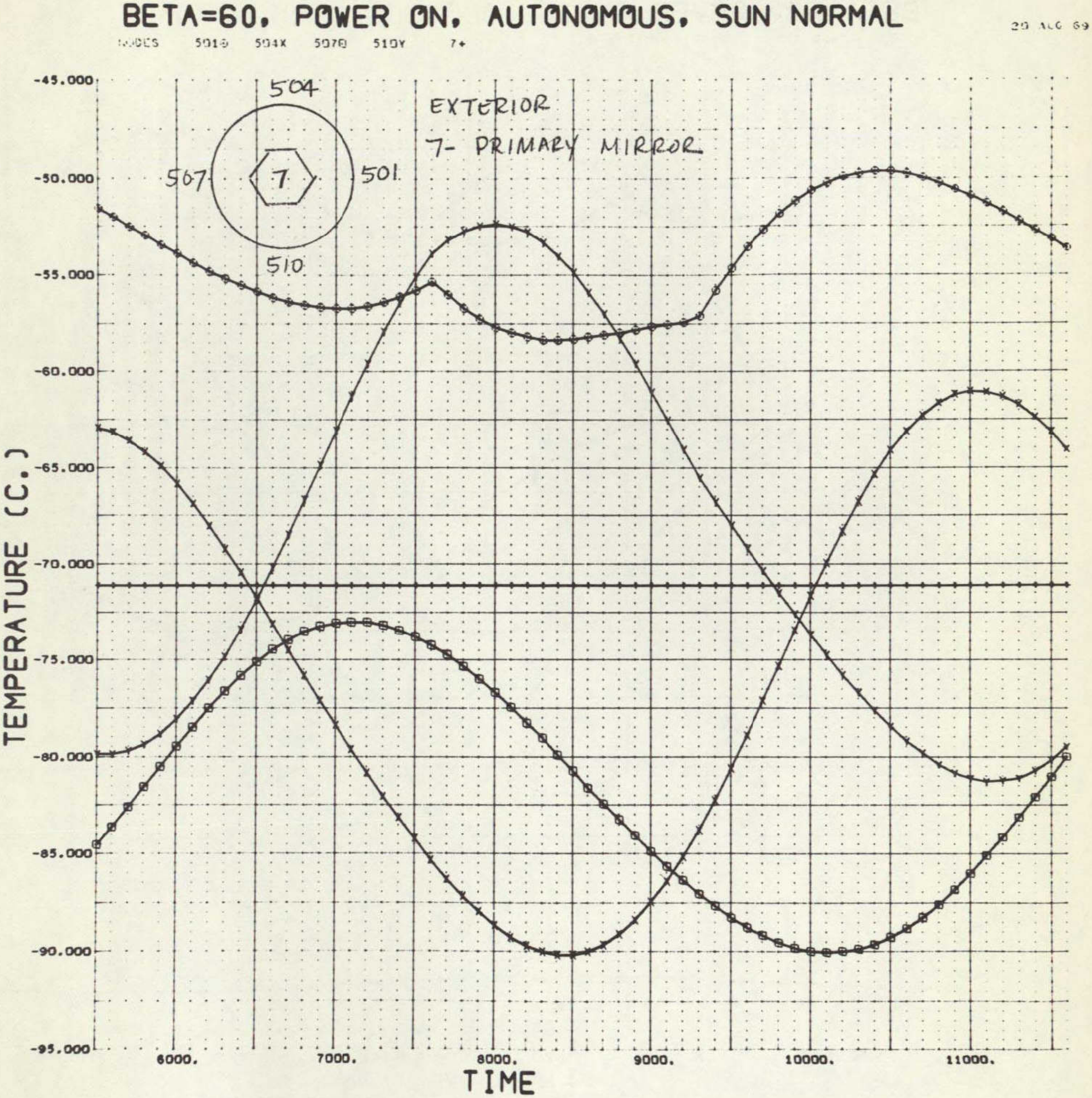

Fig. 69 (k) LTEP Thermal Performance (Beta = 60, Power On, Autonomous-K)

5.2.5 Conclusions and Recommendations

Although many missions and configurations were analyzed, several configurations were found either to be thermally equivalent or thermally identical which reduced the number of configurations for which detailed analysis was required. For the current LTEP mission (220 nm earth orbit, β range from 0 deg to 60 deg, and operating with power), the mirror temperature level ranges from -71°C to -84°C and the temperature gradient across the mirror is less than 1°C. There is a 3°C mirror temperature change from the docked to the undocked LTEP configuration. Also, the power dissipation in the rack raises the mirror temperature level from 5.7°C to 12.5°C.

Further thermal analyses are recommended before finalizing the LTEP design. An increase in the number of nodes on the primary mirror is necessary to obtain a better definition of the thermal gradients. Transient thermal analyses must be conducted to determine the effect of the sun cap actuation and effect of any incident solar energy. These studies would determine limiting time that the sun cap could be left open.

5.3 ASTRONAUT PARTICIPATION

The primary purpose of the astronaut participation analysis was to update the descriptions of astronaut operations and to refine the crew operations time lines from those presented in the Optical Technology Experiment System (OTES) Phase II Final Report (Reference 7-11). These changes primarily result from the following influences:

(a) Current AAP configuration and mission plan (dry workshop).

(b) Current optical technology experiment definition.

(c) Requirement for development of in-space maintenance technology for large telescopes of the future.

This analysis was oriented to the two-meter LTEP-ATM on the second AAP cluster in the 1974-75 time frame making maximum utilization of applicable solar ATM hardware, techniques and procedures. Because of a lack of current definition of the second cluster mission profile, those of the first cluster were used for this analysis. This is considered a good approximation, since a minimum change from the first cluster will be desired. The assumed orbit is 220 nm decaying to 210 nm at 35 deg inclination providing an approximate 93 minute orbital period with 35 minutes in the dark (Appendix B). No requirement for an orbital drag makeup maneuver is assumed. Three manned missions are assumed with the first of 28 days and the remaining two of 56 days duration. There is a 60-day orbital storage period following the first mission and 30 days following the second. The LTEP-ATM is automatically deployed prior to manning the station in a similar manner to the solar ATM. No telescope operation during the orbital storage period is assumed.

5.3.1 Astronaut Operations

A comparison between currently planned solar ATM and candidate LTEP-ATM astronaut functions has been conducted in the categories of EVA for data retrieval and resupply, EVA for mirror segment replacement, and pointing control system operation. Substitution of the LTEP for the solar ATM does not appear at this time to impact IVA operations or watch duties. However, there is no requirement in the LTEP operation for exercise of scientific and technical judgment in the field of stellar astronomy comparable to that required of the astronauts in the field of solar astronomy during solar-ATM operation.

The following comparative analysis in the functions differing between the two ATM operations has been approached from two standpoints:

a. To evaluate the effectiveness of the AAP flight configuration as a test bed for developing astronaut operations uniquely required to support large orbiting astronomical telescopes, and

b. To estimate the commonality of astronaut functions in the two ATM applications.

5.3.1.1 EVA for Data Retrieval and Resupply. The LTEP/ATM imposes reduced requirements for this category of astronaut functions as compared with the solar ATM. In both instances the data is largely in the form of retrievable and replaceable film magazines, but a much smaller quantity of film is required for stellar as compared with solar astronomy applications. This can result in either smaller film magazines or less frequent EVA excursions but, more likely, in a combination of both. The LTEP/ATM, additionally, will require exchange of black boxes in the instrumentation bay behind the primary mirror to implement such requirements as filter changing. It is anticipated that these black boxes will be no larger or heavier than the currently planned solar ATM film magazines. Even with this additional requirement for the LTEP/ATM, the anticipated EVA load transfer and frequency requirements for these purposes will be less than for the solar ATM.

Because the LTEP film magazines and black boxes are located near the MDA end of the ATM and because of their comparable size and weight to the solar ATM film magazines, it is anticipated that the planned solar ATM workstations, translation system and film magazine transportation system will be directly applicable to the LTEP/ATM with little or no modification. In fact, some hardware can probably be eliminated because of the lack of a requirement for workstations near the end of the rack opposite the MDA (sun end on solar ATM), with the possible exception of a film magazine location used to obtain the scatterplate interferogram.

5.3.1.2 Mirror Segment Replacement. The replacement of one segment of the segmented active-optics mirror configuration is an astronaut EVA operation uniquely required to support large orbiting astronomical telescopes and differs from operations required for the solar ATM. This is a maintenance operation key to assuring longevity of larger orbiting telescopes of the future, and is one in which use of an astronaut may compare very favorably against a fully automated operation. If this mirror approach is utilized and the experiment included, the mirror segment transfer required in the replacement operation becomes an essential portion of a later on-orbit mirror segment recoating operation, and the portion placing the greatest demand upon astronaut skills. (A mirror recoating experiment has not been considered for the LTEP/ATM, since the low AAP orbit does not provide a sufficient vacuum).

The mirror segments are wedge-shaped with approximately 25 x 40 inch dimensions; each segment weighs 80 to 90 lbs. Necessary transfer cases for the segments will increase these dimensions and weights from 10 to 20 percent. The mass distribution is uniform so that the geometrical center of the package should approximate the center-of-gravity. These packages are over twice the size and weight of the magazines, and are a significant proportion of the astronaut EVA weight. Their size may prevent their movement through the airlock and, thus, external stowage of the spare segments will be required. A stowage point inside the airlock module thermal curtain would permit use of the same transfer route as used for film magazines. The solar ATM translation system will probably be applicable with little or no modification. A transportation system must be devised to handle the increased size and weight of the segment packages. Because the required transportation route appears similar, however, a modification of the solar ATM film magazine transportation system may prove adequate.

5.3.1.3 Pointing Control System Operation. An analysis has been made to determine the degree of applicability of solar ATM astronaut pointing control system operations to the LTEP/ATM. The following operations appear essentially unchanged:

a. Pointing and control system startup.

b. Nominal routine monitoring.

c. Offset pointing for ground provided coordinates.

d. RCS desaturation of CMG's.

e. ATM digital computer updates.

f. Timekeeping, 2-axis attitude reference, manual gravity gradient dump and star tracker failure contingency operations.

The following solar ATM operations are not applicable to the LTEP/ATM:

a. Offset pointing – visible solar feature selection and manual aiming.

b. Fine sun sensor readout calibration.

c. Experiment roll reference contingency operation.

d. Experiment total daylight period operation – LOS through atmosphere to sun.

e. Fine sun sensor wedge readout initialization and reset.

The following solar ATM operations are applicable when modified as indicated:

a. Attitude initialization and vehicle maneuver – much greater frequency of requirement in order to select different telescope gross LOS within which the pointing control system operates.

b. Star tracker gross positioning –greater frequency of requirement.

The contingency operations permit continued ATM functioning at near normal with astronaut manual operations substituting for failed or degraded automatic functions. The experiment total daylight period, and the fine sun sensor wedge readout initialization and reset operations compensate for misalignments resulting from atmospheric refraction effects, and from launch and ascent mechanical stresses respectively. These are misalignments in the sun sensor systems, but it is conceivable that comparable operations may be appropriate for the LTEP/ATM star sensor systems.

5.3.2 Crew Operations Scheduling

Table 24 defines major mission phases starting from the first manned launch. This scheduling provides the potential of 119 typical crew cycle days in which telescope pointing operations would be scheduled. It also provides for two mirror segment replacement operations.

The preliminary LTEP crew time line analysis, shown in Figure 70, was developed for a typical crew cycle day, which is one in which pointing operations would be conducted. The following additional assumptions and requirements were used to develop this schedule:

- Gravity gradient momentum management techniques would be used and the maneuvers would require approximately one-third of the total mission time.

- A minimum of six revolutions in stellar aiming attitude would be tolerated without CMG saturation. This will include any momentum buildup resulting from initial vehicle reorientation required for gross telescope aiming.

- Watch duties to include periodic system checks and routine system status monitoring must be performed continuously at the Multiple Docking Adapter (MDA) crew station, but can occur simultaneously with periods of experiment operation. This is more feasible than with the solar ATM, because of the lack of an experment operation as continuously demanding as the solar disc patrol mode.

- Telescope aiming operations to include the 1/100 arc-sec telescope pointing technology experiment and stellar data acquisition observation must be accomplished during periods of maximum quiescence with respect to vehicle perturbating influences such as crew motion, other experiment operations, and Cluster systems operations.

- A 24-hour digital cycle will be maintained for the crew with a daily sleep period of 8 hours, rest and recreation period of 1.5 hours, and three daily eating periods of one hour each for each crewman.

Table 24

MISSION PHASE SCHEDULE

Mission	Day	Activity
Manned No. 1	1 – 2	Launch through station activation
	*3 – 25	Experiment operation
	26	Data recording retrieval EVA
	27 – 28	Station deactivation through re-entry
Storage No. 1	29 – 88	On-orbit storage
Manned No. 2	89 – 90	Launch through station reactivation
	91	Data recording media resupply EVA
	92	Rest and system checks
	93	Mirror segment replacement EVA
	*94 – 141	Experiment operation
	142	Data retrieval EVA
	143 – 144	Station deactivation through re-entry
Storage No. 2	145 – 174	On-orbit storage
Manned No. 3	175 – 176	Launch through station reactivation
	177	Data recording media resupply EVA
	178	Rest and system checks
	179	Mirror segment replacement EVA
	*180 – 227	Experiment operation
	228	Data retrieval EVA
	229 – 230	Station deactivation through re-entry

*Typical crew cycle days.

- All sleeping, eating, and rest and recreation will be in the Dry Workshop (DWS).
- Approximately 24 manhours per day will be available for experiment operation.
- Stellar observation periods will be continuous through day and night portions of the orbit.
- Stars for observation will be selected from those which are not obscured by the earth or are not in a ±45 deg cone angle relative to the direction of the sun.
- Maximum continuous observation (minimum reacquisition requirement) is desirable for each star to be observed.

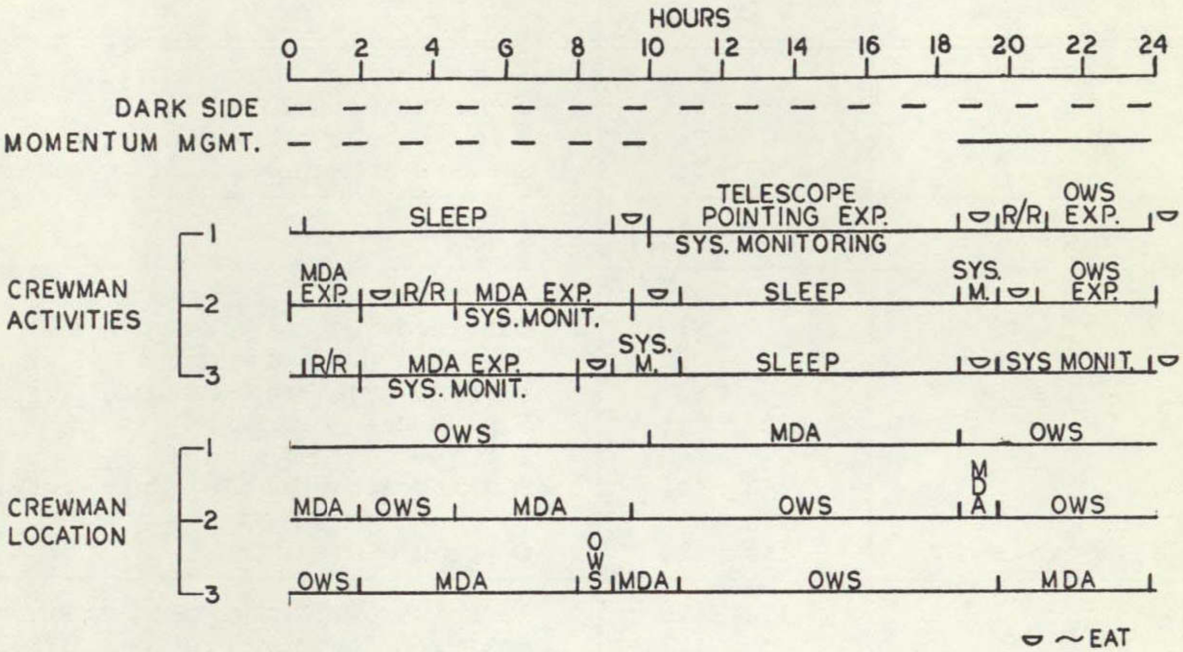

Fig. 70 Typical Crew Schedule for Pointing Experiment Day

The first two assumptions are believed valid for the orbital flight modes used for the solar ATM in the first AAP cluster. Analysis is required, however, to establish the momentum buildup as a function of the orbital flight modes (attitudes) required for gross pointing of LTEP/ATM toward selected stellar targets. This momentum accumulation results, primarily, from non-cyclic torques involved in maintaining desired pointing attitudes and torques deriving from initial attitude maneuvers for desired stellar pointing. This latter source might be used to unload (dump) momentum. The Thruster Attitude Control System (TACS) has not been considered for use in a primary mode for momentum management because the present candidate TACS are fuel limited in the existing designs (not a weight limitation).

Examination of the time line in Fig. 70 reveals a total time per day of a continuous 8.5 hours for telescope pointing experiments, 13 man hours for other experiments with associated crew operations situated in the DWS. This provides a total of 27.5 experiment manhours per day which compares favorably with the limitation maximum of 24 manhours when the system monitoring occurring simultaneously with experiment operations is considered. These proportions compare favorably with current planning for the first cluster missions. As much as three manhours could be switched from an MDA to DWS location for crewman No. 2 or No. 3.

The advanced biomedical and behavioral experiments which are the current top priority candidates for the second cluster mission are estimated to require 5 manhours per day in the DWS on typical crew cycle days. All three crewmen must participate, however, in the experiments with two present simultaneously. The timeline indicates that it would be difficult to have a second crewman present when crewman No. 3 is available for experiments requiring a DWS location. The time line requires two IVA excursions between the MDA and DWS for crewman No. 1, five for crewman No. 2, and six for crewman No. 3. A better balance of IVA excursions between crewmen would be desirable.

The telescope pointing operations are scheduled during the sleep period for two crewmen which should minimize interfering perturbations from crew motion, cluster systems operation and other experiment activities. Of the total scheduled period of 8.5 hours, approximately 8 hours should be devoted to actual observation with the first half-hour used for attitude reorientation, star acquisition, and experiment setup operations. This would provide a potential of 952 hours of stellar observations over the 119 typical crew cycle days in the three missions.

5.3.3 Crew Training

Unlike the solar ATM, the LTEP/ATM operation does not pose a pacing training problem for the astronauts. No exercise of scientific or technical judgment in the field of stellar astronomy is required. Furthermore, no manual fine pointing control is required. The operation primarily requires a sequence of procedures and exercise of engineering judgment concerning the operating effectiveness of the ATM systems. The solar ATM procedures trainer and mission simulator could be transitioned to the LTEP/ATM with control console instrumentation changes adding only conventional instruments, and development of new computer software. Even the new software will be simpler since there is no requirement to implement a manual control loop.

Mirror segment replacement will extend the EVA training from data package retrieval and replacement in order to handle the larger and heavier packages, and use modified aids. EVA trainers will require modification and augmentation to reflect the increased scope and difficulty of the EVA tasks.

5.3.4 Astronaut Participation Analyses Results

The following summarizes the impact of an LTEP/ATM application upon astronaut considerations as compared with the current solar ATM operations as indicated from the preceding analyses:

a. The requirements for astronaut scientific and manual control skills are reduced.

b. There are minimum IVA and control procedures changes.

c. There is an added EVA requirement, but it is a logical next step from the first cluster EVA requirements.

d. The quiescence requirement during telescope operation adds a major crew activity scheduling restriction.

e. There are minimum requirements for new or modified crew systems and training equipment.

Follow-on (Phase B) effort is summarized in Section 6. It includes a recommendation for generation of the following items:

a. Astronaut task/equipment analyses.

b. Astronaut operations time lines.

c. Conceptual designs and development planning for new crew systems equipment requirements, particularly task aids.

d. Training plan, and training equipment conceptual designs and development planning, to satisfy new requirements.

e. A detailed momentum management analysis and plan as a function of the total mission flight profile.

f. Conceptual designs and design integration of the crew systems task and work aid equipment (transportation system) necessary to support the mirror segment replacement operation.

The astronaut operations described in the preceding paragraphs were reviewed with cognizant NASA Manned Spacecraft Center (MSC) crew systems personnel at Houston on 30 and 31 October 1969.

5.4 RESOURCE PLANS

5.4.1 Preliminary Technical Plan

The Technical Plan for LTEP summarizes the other plans (Subsystems, Facilities, Test, Schedule, and Cost), but to a broader level of detail. It identifies the major classes of engineering, manufacturing, and testing activities, the major classes of flight and support hardware, and the schedule and cost increments appropriate to each class. The plan provides a discussion of the assumed baseline and concurrent inputs to the LTEP Program, as well as the assumed NASA guidelines, ground rules, and constraints. Statements of the objectives to be achieved in each program phase and major activity class are followed by discussion of the methods recommended for achieving them. As a summary of other plans, the Technical Plan displays identifiable activities and outputs from the assumed early 1970 go-ahead for Phase B through an assumed launch in 1975.

Approach. The LTEP development poses many unique challenges to total systems management and to spacecraft development resulting from the complex technical and administrative interfaces between spacecraft and optical disciplines and the complexities of coordinating LTEP activities at Huntsville, Houston, and Cape Kennedy with a multitude of other major experiment payloads.

The LTEP Technical Plan and related subordinate plans propose to pace all spacecraft development activities and, to the extent possible, all payload integration activities to the optical subsystem development. To this end, data pertaining to launch and orbital environments and to astronaut EVA and IVA capabilities are provided when optical support requirements are being definitized in Phase B. Likewise, a scale model of the preliminary design is provided to support optical experimental investigations. Test data on flight-level spacecraft hardware will be provided before completion of optical subsystem preliminary design.

The Perkin-Elmer/LMSC approach to coordinating with other integration activities is to provide ample spans of time at the NASA centers for performing all LTEP tasks and to divide activities into segments which can be shifted forward or backward interchangeably by increments of several weeks to accommodate unforeseen schedule conflicts.

Assumptions. All data presented, conclusions reached, and recommendations made in the Resources Plans are founded on the following assumptions:

- The LTEP will be physically integrated into a modified Apollo Telescope Mount (ATM) rack assembly which, with its flexure-pivot three-axis gimbal system, and swing-links, will be GFE hardware.
- All designated Government facilities, equipment, and services, as well as designated interface engineering, manufacturing, and test support to LTEP will be available on a no-cost basis.
- Although the proposed program for the 2-m telescope concept will develop technology applicable to the development of a 3-m or larger diameter telescope system, resource requirements for a larger system are not detailed in this report.

- The LTEP telescope/rack/propulsion-support module will be carried to orbit (e.g., 220 nm) in one of four modes: (1) The SWS-II LTEP-AAP Saturn workshop; (2) The Titan IIIC LTEP-independent and unmanned; (3) The Rendezvous LTEP-independent launch/cluster operation; and/or (4) The Saturn IB LTEP-independent launch/manned capability. These modes employ one of three potential launch vehicle configurations: Saturn V, Titan IIIC or Saturn IB. (The four (4) LTEP System configurations are shown in Figures 1 and 60.)

- Spares provisioning and planned logistic resupply during orbital operations is consistent with a 2-year operational life and subsequent resupply and maintenance.

Objectives. This subsection presents some typical objectives of the LTEP Program phases (Table 25). These objectives have been developed from the broad, technical, and management goals of the total program down to detailed requirements for individual subsystems. Payload integration and qualification test operations will readily lend themselves to schedule shifts and interchanges by spans of several weeks in order to mesh flexibly with launch schedules.

It is assumed that NASA programmed support equipment, facilities, and operations will be employed in the LTEP Program. Included in this category of collateral support capabilities are ATM/Rack assembly and test areas at MSFC, MSC, and KSC; conjunctive support of mission control, experiment control, and data management operations; and collective planning of logistic resupply systems.

Methods. Methods designed to achieve the preceding objectives are summarized in Table 26. To present a cross-section of the approach, the methods shown range from broad to specific techniques for program implementation.

Product. The deliverable products of the LTEP Program are generally defined by NASA Phased Project Planning Guidelines. That is, the Preliminary Analysis Phase (A) provides intermediate and final reports of feasibility and resources; the Project Definition Phase (B) produces a complete set of preliminary functional plans and a preliminary design and analysis report; the Design Phase (C) provides a firm System Specification and a complete set of design drawings and functional plans; the Development. Operations Phase (D) generates the flight, qualification, and support hardware, as well as a set of flight reports which provide spacecraft performance and experiment results.

Reports. Reports to be provided during the LTEP Program may be summarized as follows:

- Phase A – Final Report including Feasibility Study; Multi-Concept Study, Concept Definition and Preliminary Resource Plans

- Phase B – Research Report, Design and Analysis Report, Preliminary Functional Plan, Preliminary System Specification

- Phase C – Design Report, Analysis and Test Report, Functional Plans, Firm System Specification

- Phase D – Design and End-Item Specifications, Project Status Report, Qualification Report, Operations and Training Manuals, Flight Reports

Table 25

LTEP PROGRAM OBJECTIVES

Level	Objective
Feasibility and Concept (Phase A) OTES and LTEP Programs	Investigate the feasibility of providing an experimental flight demonstration of a large space optical system capable of long-term 0.01 arc sec, diffraction-limited, stellar observation. This optical system will have sufficient operational lifetime for its performance to be confidently extrapolated over a 10-yr period.
Program Definition (Phase B)	From the various feasible concepts studied in Phase A, the single most promising concept must be sufficiently refined in Phase B to produce a Preliminary System Specification if the launch schedule is to be met. A complete set of preliminary functional plans will be provided in Phases C and D to outline all project activities.
Design (Phase C)	Design of the selected concept will be carried forward, supported by analysis and experimental testing, sufficiently to produce a complete set of design drawings and a firm System Specification. These design documents, together with updated Functional Plans for Phase D, will clearly justify and support commitment of major government funding for the development, qualification, and operation of a large stellar telescope in the period from 1971 to 1978. With respect to the development of mockups and models, a subordinate objective is to provide, at the end of the third quarter of this Phase, representative flight structures to be utilized in subsequent experimental investigations. At the time of model fabrication, design analysis will be 60 percent complete. Another subordinate objective in this phase is to provide a sufficiently complete detailed set of tool designs, except for minor subsequent revisions, so that flight hardware jigs and fixtures can be completed in the first 6 months of Phase D.
Development/ Operations (Phase D)	To the extent that the program launch date provides the time to do so, test results will be reviewed and corrective designs formulated before extensive work is accomplished on successive generations of hardware. A development and qualification program will be presented that will demonstrate, within the capability constraints of ground test facilities, that the flight hardware produced will achieve its operational performance objectives. The qualification program will provide for piecemeal generation of test results through the succeeding levels of component, subsystem, and system tests, culminating in complete integrated system tests.

Table 26

LTEP PROGRAM MANAGEMENT

Objective	Method of Achieving Objective
0.01 arc-sec, long-term observation	The technology contribution to achievement of this objective resides principally in the promised capabilities of the ATM attitude-control subsystem with its CMGs and three-axis gimbal. The optical fine pointing techniques will evolve out of the utilization of the transfer lens, the free-float system, and image movers. The addition of an independent Propulsion/Support Module permits flexible space operation independent of other support vehicles.
Refinement of a single concept design	After NASA approval, the concept definition of a telescope and the experiments will be further developed and refined by intensified analysis and design efforts. Complete concept definition of all spacecraft subsystems will be dependent on and paced by the selected experiments and primary mirror development. In the last half of Phase B all-metal mockups of portions of the spacecraft structure related to astronaut EVA tasks will be fabricated from conceptual drawings and utilized in the LMSC Biotechnology Laboratory for 0-g (dry) and underwater simulation. The human factors data thus derived will be introduced into the design of Phase C.
Development of a complete set of preliminary functional plans for Phases C and D	After first preparing a detailed master schedule identifying all principal activities and interfaces (to the extent possible in Phase B), the following plans (others may be added) will be drafted: • Management • Engineering • Configuration Control • Quality Assurance and Reliability • Integrated Test • Transportation • Safety • Schedule and Cost • Manufacturing • Facilities • Payload Integration • Logistics • Training • Launch Operations • Mission Operations • Flight Data Operations
Complete set of design drawings and a firm system specification	Achievement of this objective will be brought about by instituting a principal design freeze at the midpoint of Phase C which is paced to a simultaneous freeze of the optical subsystem interface. The design work performed in the last 6 months, supported by hardware demonstrations of certain design features, will then provide the firm design definition in support of Phase D commitment.

Table 26 (Cont.)

Objective	Method of Achieving Objective
Completion of a functional engineering model by August 1972	By developing the 2-m mirror and commencing fabrication ahead of the principal design freeze and then retrofitting the minor concept changes, this model can be completed as scheduled. After the design changes brought about by design-analysis results and interface feedback from Perkin-Elmer are finalized, Perkin-Elmer will update the models in their shops for the remaining year of their optical subsystem experimentation.
Complete tool design definition at the end of Phase C	By commencing tool design at the time of principal design freeze and pacing the definition of tool configurations to finalization of the spacecraft design, this activity will be essentially completed by the end of 1971.
Minimal overlap of testing and fabrication of next-generation hardware	This principle is emphasized to the maximum extent possible in the early portions of Phase D. For example, structural and thermal test results of the design engineering model (non-tooled) will be available before fabrication of the first (tooled) structural model. Likewise, test results of the latter model are available before final tool modifications leading to fabrication of the qualification prototypes. As development progresses, confidence in system reliability increases and greater overlap is acceptable.
Flight-hardware qualification program	Because of the particular criticality of the optical subsystem performance and its dependence on precisely known and controlled spacecraft parameters, the LTEP qualification program provides full-scale verification testing to every level of Phase D hardware generation, including the flight unit itself.
Provision for flexible scheduling of integration operations	To satisfy requirements for full and unbroken utilization of integration/test facilities and personnel, their master schedules will show, at least by 1971, all the operations required to support LTEP. Because of the complexity of coordinating the large number of spacecraft and operations increments, it will probably be necessary to reallocate relatively large blocks of time and support to maintain launch schedules. Therefore, each major LTEP integration or test operation will be separately planned, specified, and implemented to permit drastic schedule shifts. For example, if the MSFC structural test facility becomes loaded, work can commence instead on instrumentation of the thermal qualification unit.

Flight Hardware. Flight hardware comprises not only the LTEP Module (Telescope Assembly, Modified ATM rack and Propulsion/Support Module but also the launch vehicles, orbital cluster spacecraft elements, and the periodic logistic resupply flights. Some flight hardware will be developed under the LTEP contract; other items will be provided GFE from other contract outputs; still other hardware items will be modified from GFE.

Table 27 identifies flight hardware by title and function, and indicates whether it is LTEP new development, Government-furnished, or LTEP modification of GFE.

Table 27

FLIGHT HARDWARE

System	Alternate mode	Subsystem	Function	*Class/ Resp.
	All	Optic Subsystems	Experiment Payload	P-E
LTEP Module	All	Telescope Structure Assy	Structural and Mechanical	LMSC
	All	Rack (ATM Modified)	Telescope Support	GFE/MSFC
	All	Solar Arrays (ATM Mod.)	Solar Energy Collect.	GFE/MSFC
	All	Solar Array Rotational Mech	Stow and Erect Arrays	LMSC
	All	Propulsion/Support Module	Space Maneuvering Subsystem Power Source Inertial Stability	LMSC
	4	MOTEL	EVA Cell	LMSC
Saturn IB	4	Adapter-Upper Stage	Transition of Loads	LMSC
	4	Adapter-Fairing Extension	Enlarge Payload Volume	LMSC
	4	Payload Fairing	Enclose Payload	LMSC
Saturn V	1	Adapter-Fairing Extension	Enlarge Payload Volume	LMSC
	1	Payload Fairing	Enclose Payload	GFE
Saturn IB/V	1&4	Launch Vehicle Modif.	LTEP Adaptation	GFE/MSFC
Titan IIIC	2&3	Adapter-Upper Stage	Transition of Loads	LMSC
	2&3	Payload Fairing	Enclose Payload	LMSC
LCSM	3&4	Logistics Comm. Serv. Module	Resupply/Maintenance	GFE
OWS	1	Orbital Workshop	Manned Experimentation	GFE
AM	1	Air Lock Module	Egress OWS	GFE
MDA	3	Multiple Docking Adapter	Docking/Attachment	GFE

*Class/Responsibility:
GFE = Government Furnished Equipment
/MSFC = MSFC Responsible to Accomplish
P-E = New Development by Perkin-Elmer
LMSC = New Development by LMSC

A further definition of the LTEP flight system is provided in Table 28.

Table 29 lists the classes of support hardware and identifies certain major equipment items on each class. For each item, Table 29 indicates whether it is newly developed, already existing, or Government furnished.

Plan. In this section, broad classifications of tasks, schedules and costs are delineated:

Tasks

Phase A

- OTES (Part I) – Experiment Study and Feasibility Analysis
- OTES (Part IA) – Conceptual Definition and Trade-Off
- OTES (Part II) – Conceptual Refinement
- LTEP – Concept Refinement and Adaptation to SWS

Phase B

- Research
- Spacecraft Modification and Preliminary Analysis
- Preliminary Design
- Development Planning

Phase C

- System Integration
- Preliminary Design
- Design Analysis
- Tool Design (Primary)
- Tool Manufacturing Plans
- GSE Design
- Model Fabrication
- Experimental Testing
- Development Testing
- Development Planning
- Report Preparation

Phase D

- System Integration
- Final Design
- Design Analysis
- Design Support
- Tool Fabrication (Primary)
- Tool Design (Secondary)
- Tool Fabrication (Secondary)
- Model and Prototype Fabrication
- Quality Assurance and Reliability
- Development Testing
- Qualification Units Fabrication
- Flight Unit Fabrication
- Handling and Transportation
- Spacecraft Integration Liaison
- Qualification and Acceptance Testing
- Training Liaison
- Logistic and Spares Operations
- Prelaunch Checkout
- Launch Operations
- Flight Operations
- Data Acquisition and Reduction
- Data Processing and Reporting

5.4.2 Subsystems Resources Analysis

In general, the LTEP Module subsystems will utilize space-qualified hardware and/or proven hardware concepts with new designs tailored to special dimensional constraints of the LTEP system. In certain instances, new development will be required, not for validation of the concept but, rather, for verification of the LTEP hardware application. The following is a description of the major subsystem elements requiring special development and/or testing.

5.4.2.1 Structures and Mechanisms. Conventional sheet-metal welded construction will be utilized. Because of the relatively thin-wall thickness and the large diameter of the telescope tube, deflection characteristics must be verified, preferably on full-scale specimens. The extension mechanism and the extend-lock system also must be verified.

a. Thermal Distortion. The telescope tube in orbit will be subjected to temperature gradients which will tend to warp the structure. Typical cylindrical sections will be fabricated and exposed to simulated orbit thermal conditions to determine structural response and tendencies to induce skin buckling. Stringer-stiffened skin will be compared to truss-sandwich, honeycomb sandwich, and ring-stiffened skin.

b. Extension Mechanism. A working breadboard of the screw-jack extension mechanism will be fabricated and tested to verify synchronization of extension jacks, capability to open to an aligned position, and capability of locking in stowed and full-open positions.

c. Extend Locks. Segments of full-size end rings of the telescope tube sections will be fabricated and tested to assure the adequacy of the pyrotechnically actuated ring lock-pins. Following successful conclusion of the detailed testing, a set of mating rings will be fabricated and the locking devices tested (6 per ring). Rigidity of the pin-locked rings will be verified by load/vibration tests; structural deformations, degradation of ring-mating, and structural alignment of tube sections will be determined.

d. Structural Alignment. A full-size working model of the extendable telescope tube will be fabricated, utilizing worst-case tolerance conditions in ring mating parts, mechanical stops, and other elements affecting alignment. The tube sections, with simulated optical elements installed, will be extended (by the extension screw jacks if available) and the tube section locked. Loads, simulating the anticipated maximums in orbit, will be applied and deflections of structure and optical elements observed before, during and after loading.

Table 28

FLIGHT SYSTEM BREAKDOWN

SYSTEM LEVEL 1	SYSTEM LEVEL 2	SYSTEM LEVEL 3	SYSTEM LEVEL 4
Large Telescope Experiment Program	Telescope Subsystem	Structure and Mechanisms Subsystems	Primary Mirror Support Fixed Shell Section Telescoping Sun Shade Sun Shutter Assembly Equipment Compartments Secondary Mirror Support Quartz-Rod Spacer Assembly Gimbal Disengage Assembly CG Positioning Assembly Launch Caging Assembly
		Optics Subsystem	Experiment Element
	Rack Subsystem	Gimbal Subsystem	Structural Assembly Pitch Actuator Assembly Yaw Actuator Assembly Roll Actuator Assembly
		Attitude-Control Subsystem	Control Moment Gyros CMG Control Electronics Star Tracker and Electronics Command Control Assembly CMG Inverter Assembly
		Electrical Power Subsystem	Solar Panels Electromechanical Actuators Charge Controller/Battery/ Reg. Modules Control Distributor Solar Power Distributor
		Rack Structure Thermal Protection Subsystem	Basic Structure Struct. Mod. Kit Assembly Insulation Assembly
		Magnetic Suspension System	Experiment
	Experiments Subsystems	Various	Experiments

SYSTEM LEVEL 3 ITEM DESCRIPTIONS

Gimbal Subsystem. Pitch/yaw rings and roll track are actuated in three axes to provide ±2.5 arc sec pointing; rate gyro pickoffs provide feedback to attitude-control subsystem.

Attitude-Control Subsystem. Within the deadband of the CSM reaction control system, the control moment gyros absorb from and retransmit angular momentum to the entire AAP cluster to reduce the deadband; three star trackers provide coarse and fine error signals.

Electrical-Power Subsystem. Designed for separate solar panels for power generation when in an Independent mode; the EPS contains sun-tracking solar panels, rechargeable batteries, and power switch gear.

Rack Structure. The basic rack structure is that of the ATM. Additional structure is added for launch caging and the magnetic suspension assembly. Unnecessary outriggers are removed.

Thermal-Protection Subsystem. The insulation assembly is a new development keyed to the requirement for a 2-m mirror.

SYSTEM LEVEL 4 ITEM DESCRIPTIONS

Primary Mirror Support. Supports the mirror and its actuators; provides thermal and dynamic isolation.

Telescoping Sun Shade. Two nested tubular sections extend on orbit to provide visual and thermal protection from the sun.

Sun Cap Assembly. A hinged lid on the end of the tubular sun shade prevents sunlight from entering the tube, when closed, and during some telescope orientation, when open.

Equipment Compartments. Six modular wedge-shaped containers around a central cylinder; contains electro-optical subsystems.

Secondary Mirror Support. Structure that supports mirror and its servo actuators.

Quarts-Rod Spacer Assembly. Mechanism that supports and positions.

Figure Sensor Support. A structure attached to outer tube section which supports the Figure Sensor package.

Gimbal Disengage. A mechanism to slide the fixed shell section 8 in. (approx.) out of the gimbal until engaged by the magnetic suspension assembly.

CG Positioner. A mechanism to shift a heavy battery rack longitudinally; shifts nominal telescope CG from the plane of the gimbal flexure pivots to the plane of the experimental magnetic suspension system.

Launch Caging. An ejectable structure that transmits launch-induced forces into the SLA, bypassing the lightweight, nested telescope.

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Table 29

LTEP SUPPORT HARDWARE

CLASS	ITEM
Research and Engineering	Zero g and underwater metal partial mockups for EVA simulations Mirror tests
Manufacturing Tooling	Master tool assembly fixtures and jigs for: • Three tubular shell sections • Mirror base • Seven equipment compartments • Rack structure modifications Various jigs, clamps, fixtures, frames, templates and special tools.
Development Test Prototypes and Equipment	Full-scale wood mockups Early (Preliminary Design) full-scale engineering model (one) Mechanism breadboards Thermal insulation and partial structure breadboards Test instrumentation, apparatus, data recorders, computer LMSC shake and shock tables, acoustic chamber, thermal/vacuum chamber
Qualification Test Prototypes and Equipment	Early (Final Design) full-scale engineering model (one) Structural test model; the first tooled production unit Thermal test model GSE checkout console to be used for integrated system runs in conjunction with the RCA-110 computer at MSF Various test instrumentation, apparatus, and fixtures MSFC shake and shock tables and acoustic chamber MSC Chamber A (thermal/vacuum) with its associated operations control and data processing equipment
Acceptance Test and Checkout Equipment	Vertical stand used at MSFC for static balance (same as the first vertical stand listed below under Handling and Transportation Equipment) GSE checkout console to be used for integrated system runs in conjunction with RCA-110 computer at KSC ACE computer for launch pad system runs
Handling, Transportation, and Launch Equipment	Vertical support stand for deployment tests in Sunnyvale; also used at MSFC for weight, inertia, and balance determination of deployed telescope Vertical support stand for use in MSC Chamber A; thermal/vacuum testing of telescope/rack/LM Various support stands and dollies used in manufacturing testing Various containers, frames, and dollies used for transcontinental shipment Guppy or Super Guppy airplanes; ocean-going barge and tugboat cranes, jibs, gantry, hoists, umbilical masts, etc. at KSC
Crew Training Equipment	Metal structural mockups used in Phase B research will also be used for EVA astronaut training at Sunnyvale or Houston MOTEL structure and panel for EVA training use (Mode 4 only) Structural qualification model used for KSC ground crew training after qualification is complete Thermal qualification model used for manned mission simulation in Chamber A and for general flight crew familiarization
Launch Vehicles and Flight Support	Launch Vehicles and Flight Support will be dictated by the Optional Mode selected. See Figures 1 and 60 Logistics spares; such as star trackers, CMG's, rate gyros, gimbal actuators, film cassettes and batteries. Logistic resupplyof crew, food, atmosphere, reactants, and propellant. Recovery fleet
Mission and Experiment Control	Kennedy tracking and control (launch) MSC Mission Control Manned Space Flight Network (MSFN) MSC Operations Control
Data Management	MSC Data Center

5.4.2.2 Propulsion Subsystem. The majority of the thrusting components and propellant feed and pressurization elements are space-qualified. Because of long-term life requirements, however, a few require special development testing. Typical examples are:

a. Bladder Tanks. Long-term cycling tests will be run on prototype tanks to assure no degradation of materials by the propellant and to verify the capability of bladders to sustain repeated operations.

b. Thrusters. Long-term hot-fire cycling tests and cold valve on-off tests will be run on the selected thrusters to verify the capability of sustaining mission cycling profiles.

5.4.2.3 Electrical Subsystem. The newly-designed solar array rotation mechanism will require development. Load testing of the mechanism and an attached ATM Solar Array (or simulation thereof) under orbit dynamic conditions will be accomplished. Long-time cycling of the mechanism will also be conducted to reveal any mechanical wear-out modes.

5.4.2.4 Control Subsystem. Following a complete analysis of the subsystem, comprising the ATM Rack CMG's and fine-pointing control system and the telescope gimbal rings, a simulation run will be made utilizing breadboarded hardware and dynamically simulating the LTEP Telescope Assembly. System responses and pointing accuracies and stabilities will be verified.

5.4.2.5 Communications and Instrumentation. The primary development problem with the C&I subsystem involves verification of long-life-operation capability. Accelerated cycling tests on a system breadboard will be accomplished and failure modes recorded and analyzed. Replacement of failed components will be made each time and tests continued.

5.4.3 Facilities Plan

A preliminary investigation was made of the facilities required to support the LTEP experiment and spacecraft integration. Analyses were made to:

- Identify general and special LTEP facility requirements
- Determine which existing government, Perkin-Elmer and Lockheed facilities are capable of effectively supporting LTEP functions
- Establish preliminary cost and schedule requirements for facility augmentation and activation

The study approach considered the accommodations necessary to support the following general LTEP activities:

- Engineering – office, desk and board, and full-scale mockups
- Fabrication and subassembly – LTEP and associated hardware buildup and subassembly

- ATM rack modification

- LTEP Module integration – final installation of Telescope Assembly and Propulsion/Support Module

- Developmental testing, quality assurance, and other general support

The results of this analysis provided the foundation for the facilities plan described in the following paragraphs.

5.4.3.1 Basic LTEP Facility Requirements. The basic space requirements to support Perkin-Elmer and Lockheed LTEP activities represent an analysis of current program schedules and manpower forecasts. Facility requirements are categorized by organizational areas and include space required in Huntsville, Sunnyvale, Norwalk, and sites near KSC and MSC. Various levels of environmentally controlled areas are provided at the Perkin-Elmer and LMSC facilities and will adequately support the LTEP.

Specialized Test Capabilities. Requirements for specialized test capabilities to support the LTEP include a vertical vacuum optical tunnel; class 100,000, class 10,000, class 100 clean rooms; a large capacity thermal/vacuum chamber; a vibration testing; and an anechoic chamber. It is currently planned to utilize the Space Optics Facility at Perkin-Elmer in its entirety and specialized test facilities recommended by LMSC and summarized in Table 30.

The Perkin-Elmer Space Optics Facility was designed and built specifically for the LTEP as a model space optical project that would require specialized and unique facilities. The special capabilities of this facility are shown in Table 31. The breakaway concept of the LTEP facility is shown in Fig. 71. The costs for this facility are not included in the project costs on the assumption that this building could be cleared of the projects by the time the LTEP is ready to go into Phase C (i.e., in early 1971).

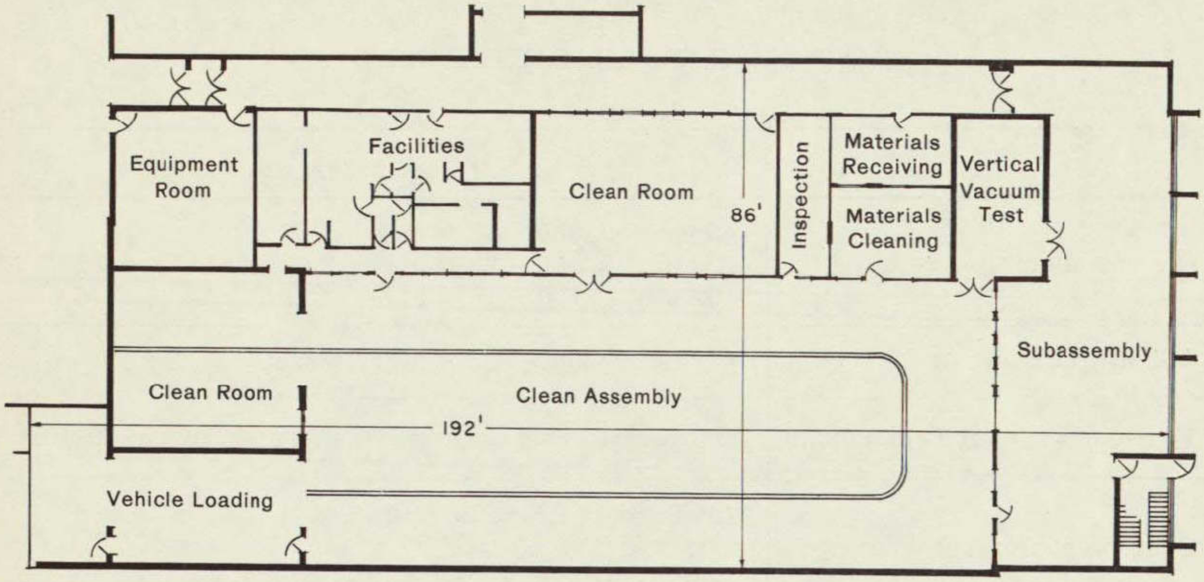
LTEP Facility Plan Options. Two facility support plans have been evolved which accomplish a basic objective of sending the LTEP Module to KSC in a condition "ready for flight" except for assembly to major launch components and minor checkout of systems. The primary P-E/LMSC plan provides for final integration of the LTEP into the modified ATM rack to be accomplished in NASA/MSFC Building 4708 at Huntsville.

The plan also provides for an LTEP interface management and liaison engineering office in the Lockheed-Huntsville facility and for the primary spacecraft engineering and manufacturing in the Lockheed-Sunnyvale Plant. A concept of the MSFC-Lockheed Huntsville Site Plan recommended for the AAP program is shown for reference in Fig. 72.

Table 30

SPECIALIZED TEST FACILITIES

Facility	Order of Preference	Specimen Size	Description
THERMAL/VACUUM CHAMBERS			
Large Capacity			
• NASA Manned Spacecraft Center, Houston, Texas	1	40 ft dia x 75 ft ht (150,000 lb)	10^{-5}, solar and cold simulation – man-rated
• Arnold Engineering Development Center, Tullahoma, Tennessee	2	20 ft dia x 50 ft ht	10^{-9} torr, solar and cold simulation
• Lockheed HIVOS Chamber, Bldg. 104, Sunnyvale, California	3	12 ft dia x 15 ft ht	10^{-6} torr, solar and cold simulation
• Lockheed Cryogenic Space Flight Simulator, Santa Cruz Test Base, California		15 ft x 25 ft	10^{-6} torr, cold simulation
Medium Capacity			
• MSFC, Bldg. 4708, Huntsville, Alabama	1	15 ft dia x 20 ft	10^{-6} torr, vacuum
• Lockheed TASC, Bldg. 104, Sunnyvale, California	2	6 ft x 25 ft	10^{-6} torr, solar and cold simulation
• Lockheed HATA, Bldg. 102, Sunnyvale, California	3	180 cu ft	10^{-5} torr, solar and cold simulation
Vibration Testing			
MSFC, Huntsville, Alabama	1	60 ft x 60 ft x 90 ft	Six 10,000-force-lb thrusters
		100 ft x 100 ft x 360 ft	Thruster for dynamic testing of Saturn V
		Subsystem and component	28,000-force-lb-shaker
Manned Spacecraft Center, Houston, Texas	2	65 ft x 85 ft x 30 ft ht	22,000-force-lb shaker; 30,000-force-lb-shaker (can be coupled)
Wyle Laboratories, Huntsville, Alabama	3	160 ft x 50 ft x 60 ft	Eight 50,000-force-lb hydra shakers (can be coupled)
			Three 200,000-force-lb hydra skaher Systems
Lockheed, Sunnyvale, California	4	16 ft dia x 25 ft	Two 30,000-force-lb shakers (can be coupled)
Large Acoustic Reverberation Chambers			
Wyle Laboratories, Huntsville, Alabama	1	25 ft x 55 ft 45 ft x 55 ft	Frequency range 20 to 10,000 cps, maximum overall sound pressure: 155 db, 20,000 acoustical w
Manned Spacecraft Center, Houston, Texas	2	30 ft x 85 ft	Frequency range 30 to 10,000 cps, maximum overall sound pressure: 171 db, 160,000 acoustical w
MSFC, Huntsville, Alabama	3	18 ft 15 ft x 20 ft (est) 4846 cu ft	40,000 acoustic w
Anechoic EMC Chambers			
MSFC, Huntsville, Alabama	1	33 ft x 33 ft x 120 ft	Assumed to satisfy MIL-I-26600
Manned Spacecraft Center, Houston, Texas	2	55 ft x 55 ft x 150 ft	Reflection of RF fields from -30 db to -55 db at 3000 Mc and above
Lockheed, Sunnyvale, California	3	30 ft x 30 ft x 60 ft	Meets MIL-I-26600



Overall Facility View

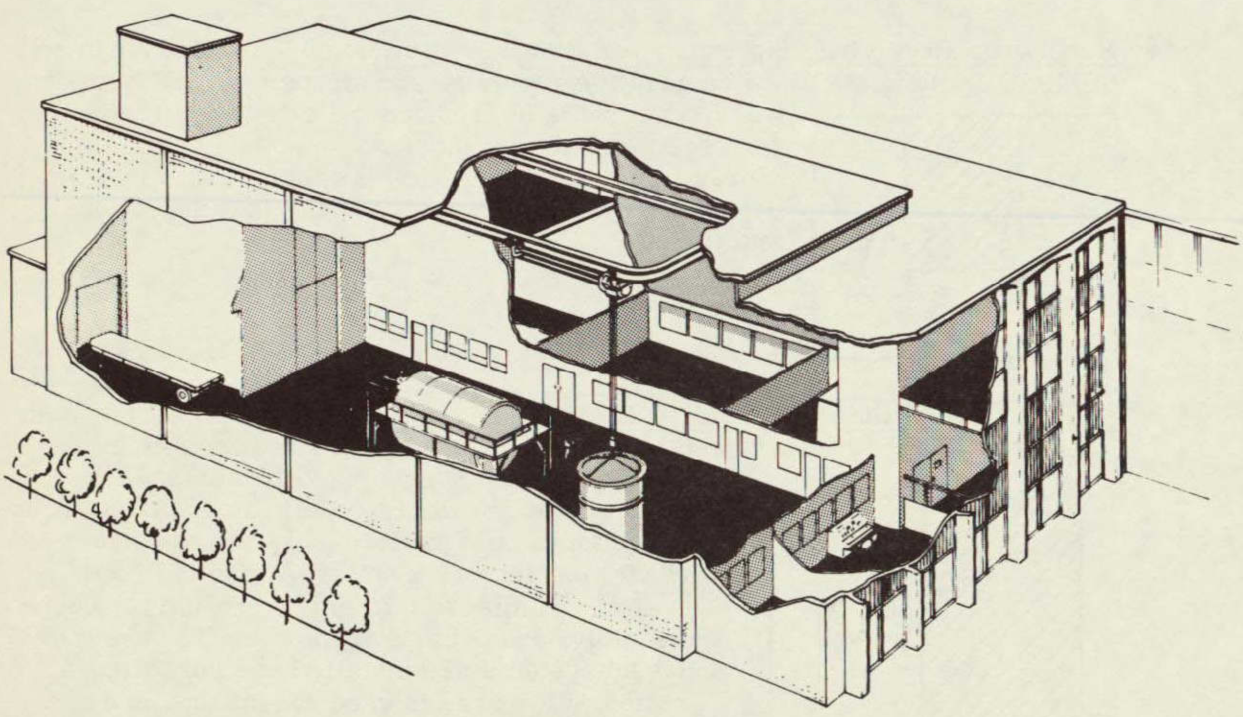


Fig. 71 Perkin-Elmer Space Optics Facility

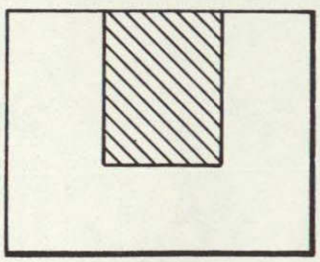
Table 31

BASIC FACILITY CHARACTERISTICS*

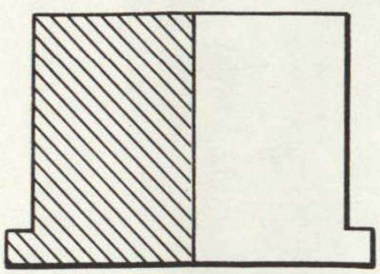
Area	Characteristics
Clean Assembly Areas	Class 100,000 – 28 ft high, 6000 ft^2 Class 10,000 – 28 ft high, 900 ft^2 Class 100 – 10 ft high, 900 ft^2
Vehicle Loading Area	Class 100,000 – 35 ft high, 600 ft^2
Vertical Vacuum Test Tunnel	Capacity to Test Optical Systems up to 10 ft diameter
Equipment Control Area	Remote operation of equipment in clean room Windows for monitoring operations

Concepts of the buildings comprising the Payload Integration Facility in Huntsville are as follows:

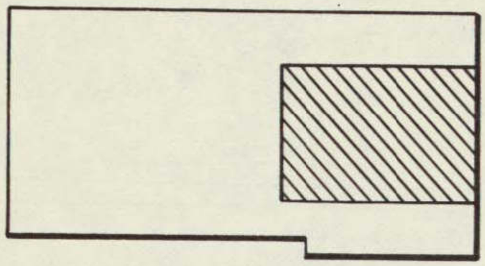
- Receiving, Receiving Inspection, and Storage – Building 4752. The north end of MSFC Building 4752, to be used for receiving and storage of AAP hardware, is capable of handling the LTEP requirements for receiving, inspection, and shipping container storage. Existing facilities in this building provide capability for comprehensive receiving inspections and tests.



- ATM Rack Modification & LTEP Major Assembly – Building 4755. The south bay of the MSFC Vehicle Assembly Building (4755) is utilized for modifying the ATM rack. Adequate overhead handling capacity, sealed floors, and filtered airconditioning system would provide adequate conditions for LTEP manufacturing activities and the required level of cleanliness. In this area, the telescope assembly, Propulsion/Support Module are mated and subsystems are installed and verified. A section of the area is used for mockup and systems development tools to verify design accuracy.



- Experiment Installation and Integrated Systems Test – Building 4708. Modifications planned for MSFC Building 4708 will permit its use for LTEP experiment installation and for integrated systems test. Adequate height, overhead handling equipment, existing hydraulic, pneumatic and utilities support, as well as RCA 110-A checkout equipment are presently available. A plastic-type enclosure will be utilized to maintain the environmental control of the area. In addition, Class 1 cleanrooms and a Class 2 modular-type laminar flow cleanroom will be provided for stringent experiment requirements.



5.4.3.2 Alternate LTEP Facilities Plan. The alternate plan provides for the LTEP Integration Facility as well as management, engineering, and manufacturing support to be located in Lockheed-Sunnyvale facilities as shown in Fig. 73. Program integration and liaison activities would be located in Huntsville in Lockheed-furnished office space.

Lockheed-Sunnyvale Building 159 is a new space-vehicle manufacturing facility and would be utilized in the event that the Alternate Facility Plan is selected. Two high bays provide 56,250 ft^2 for carrier modification, subsystems and experiment installation, and integrated systems test. Complete overhead crane coverage is provided with with 25-ton capacity and 40-ft hook height. The bay used for experiment installation and integrated systems test is adjacent to the checkout equipment area and is environmentally controlled to Lockheed Class O-M cleanliness level. Building 159 includes a two-story bay adjacent to Integrated Systems Test which will provide 26,000 ft^2 for housing checkout equipment, test engineers, experimenter, and reliability and operations personnel. Design engineering and indirect support will be housed in nearby existing buildings at Sunnyvale. Existing Lockheed facilities that can be used at Sunnyvale include:

- Building 102: computer center
- Building 103: machine shop and processing
- Building 104: component testing
- Buildings 151 and 152: electronic fabrication and test

5.4.3.3 Facilities Support Plan.

Spacecraft Fabrication and Assembly – Fabrication of tools and hardware components for the LTEP Program can be provided by the Lockheed Sunnyvale general support shops in Buildings 103, 151, and 152. Assembly of LTEP models and storage of project tooling and fabricated parts can be accommodated by utilizing a portion of Lockheed-Sunnyvale Building 152. This assembly area can be activated in three increments in conformance with the LTEP hardware development plan.

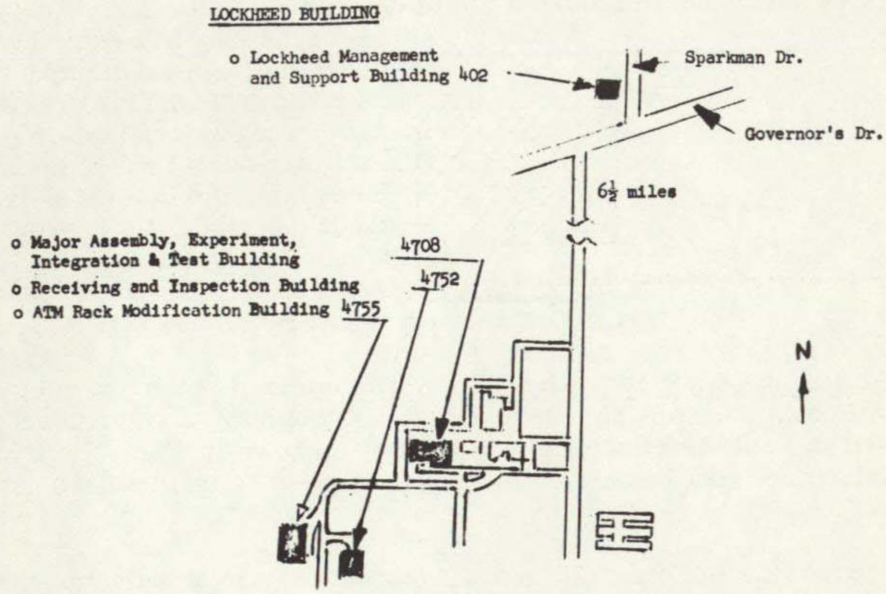


Fig. 72 MSFC/Lockheed Huntsville Facility Concept

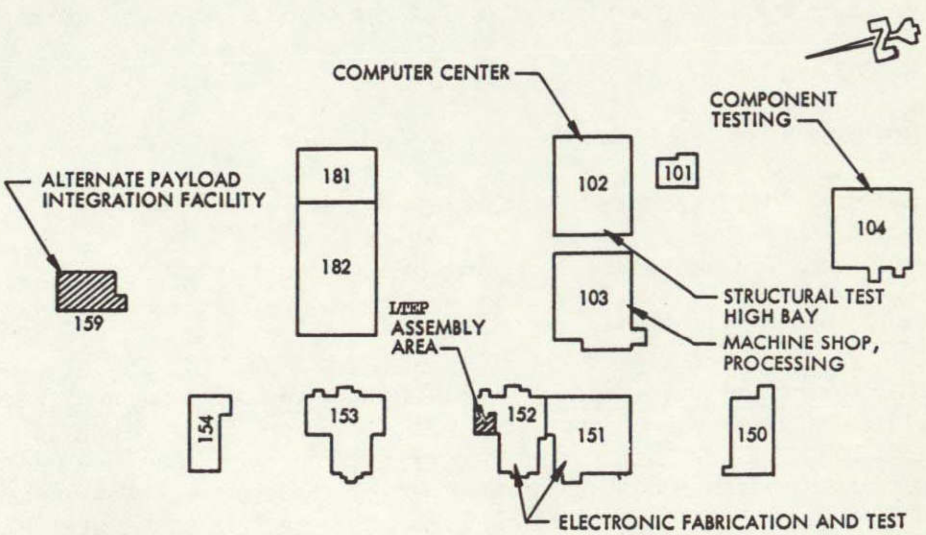


Fig. 73 Lockheed Sunnyvale LTEP Facility Plan

Initial assembly area activation would provide 2,000 ft^2 for assembly of full-scale models of sections of the scope assembly required during Phase B. The second phase activation would provide a cumulative total of 5,600 ft^2 beginning the second quarter of 1971. This activation will accommodate assembly of up to three LTEP models and provide approximately 2,000 ft^2 of storage for fabricated parts and tooling. The third and final assembly area activation in the third quarter of 1972 will satisfy the peak LTEP requirements for assembly, storage of fabricated parts and project tools, manufacturing support, and shipping and receiving. Figure 74 illustrates the use of this area to accommodate the engineering model as well as assembly of the thermal and structural test units during this peak period.

Lockheed structural testing is planned to be performed in Lockheed-Sunnyvale Building 102 Test Bay. This existing facility is completely equipped with a 60-ft high bridge crane and required test equipment. Thermal development test on segments of the LTEP engineering model will be performed in the Lockheed-Sunnyvale Biotechnology Laboratory vacuum chamber.

<u>LMSC R&D Support Facilities</u>. Several equipment facilities of the LMSC Research & Development Division are available for use on the various Lockheed spacecraft development programs. For the LTEP thermal similitude study, for example, the Thermophysics Group has developed a Space Environmental Analysis Research Chamber (SEARCH) that will provide LTEP with a capability to verify experimentally predicted orbital temperature distributions using scale models.

The chamber (Fig. 75) is a horizontal steel cylinder 8 ft in diameter by 10 ft long. Four 6 in. diameter view ports are located at the horizontal centerline, two on each side. Liquid nitrogen cold wall sections are spaced out 4 in. from the chamber wall. Both ends are equipped with lapped doors on rolling frames. A spare door is available for instrumenting new test specimens while the chamber is in operation. Each door is provided with a central 12-in. diameter quartz view port which can be replaced with an insulated feed-through plate. In addition, each door is equipped with five 6-in. diameter feed-through plates. Each door is also equipped with a vacuum-sealed actuator rod which provides up to 6 in. of axial translation or bidirectional rotation up to 200 rpm (limited by seal friction). The actuator rod incorporates a slip ring with connections for 40 pairs of instrument leads. Test specimens are supported entirely by the doors. The chamber is equipped with a single 6-in. exhaust valve which can be connected alter nately to either a 250-cfm oil lubricated mechanical pump or a 178-cfm blower. There are plans for future installation of a second 6-in. valve so the roughing pumps can be operated in parallel. There are also two finishing pumps. One pump is a 350 1/sec oil ejection pump incorporating two diffusion stages and one ejector stage. It is capable of pumping down to 10-4 torr. The second finishing pump is a 36-in., 50,000 1/sec oil diffusion pump valved in series with the ejector pump. With the ejector acting as a fore pump, the diffusion pump produces 10^{-7} torr.

The test specimen can be irradiated by tungsten-filament quartz lamps mounted inside the chamber, with total input up to 25 kw. However, the principal source of thermal radiant energy is an optically focused carbon arc lamp (on a separate rolling stand) which produces a 3-ft diameter spot 50 in. from the door. The lamp is equipped with a masking frame behind the objective lens to shape the beam to the configuration profile of the test model so as to reduce back scattering from chamber walls. The output at spot focus is equivalent to one sun irradiance, or 0.14 w/cm^2.

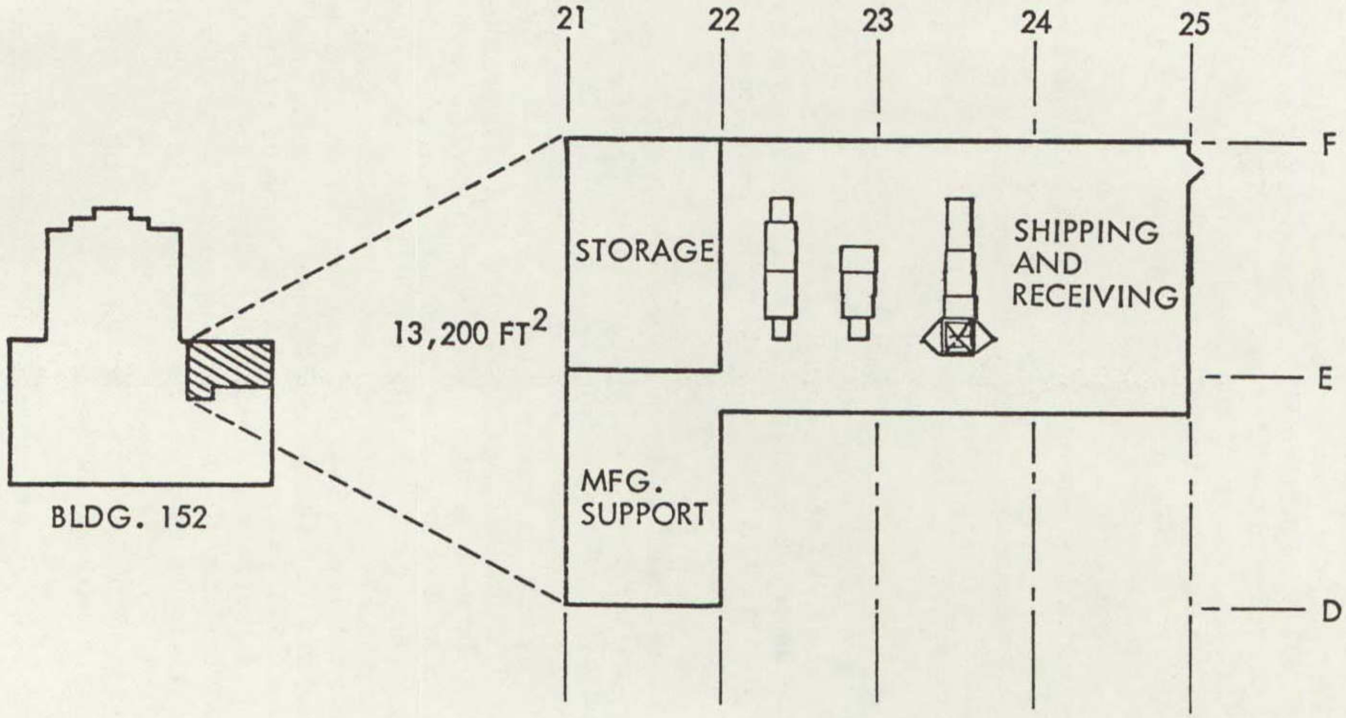


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Fig. 74 Sunnyvale Building 152 OTES Assembly Area

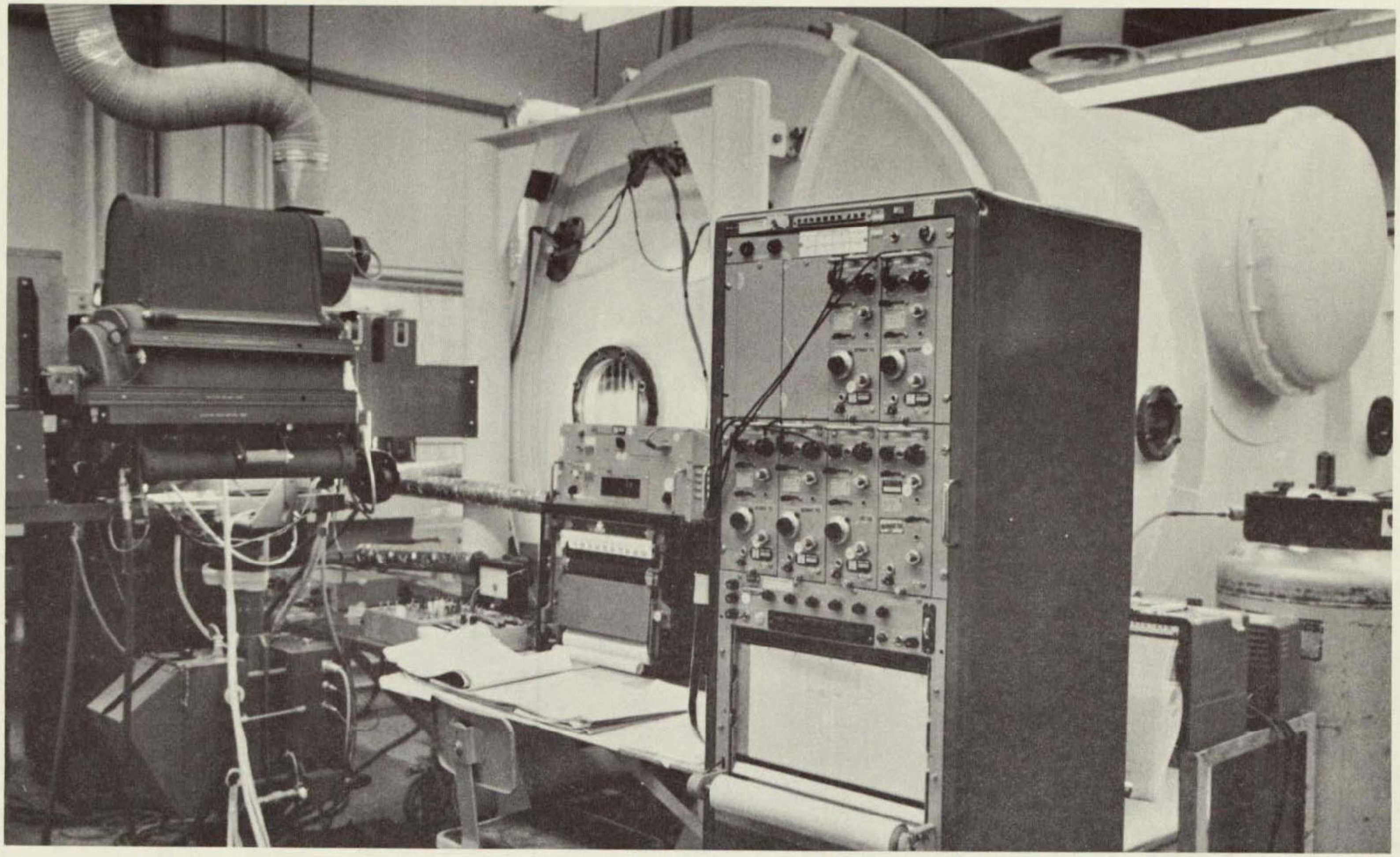

Fig. 75 Overall View of Search Chamber Showing Instrumentation in Place

The SEARCH facility was prepared to perform a thermal similitude verification for NASA-MSFC under contract NAS 8-20411. In considering the selection of a candidate spacecraft to be modeled for study in the chamber, attention was drawn to the OTES study and to the four telescope concepts then defined (0.5-m, 1-m, 2-m, and 3-m). After a period of evaluation of the four configurations, and the modeling problems which each entailed, the 2-m concept was selected as the subject. The subsequent program (Reference 7-13) substantiated results of the OTES and LTEP thermal analysis studies (Section 5.2).

5.4.3.4 LTEP Operations Support Plan.

Manned Spacecraft Center. Technical support of the LTEP program will be provided to assist the Manned Spacecraft Center (MSC) in astronaut training, conducting thermal-vacuum tests, and experiment data analysis. These activities will be in support of the MSC Mission Control Center as well as the anticipated MSC Experiment Control Center and the MSC Data Center. Office space for Lockheed personnel will be provided in the Lockheed Clear Lake facility on El Camino Real, approximately 1.5 miles from MSC. It is recommended that the large thermal-vacuum chamber, located in MSC Building 32, be employed for qualification and flight readiness testing of the integrated LTEP Module. The chamber is capable of accommodating the proposed LTEP configuration and current schedules indicate the chamber will be available at the times required.

Kennedy Space Center. Technical support will be provided to assist Kennedy Space Center (KSC) during the following operations:

- Receiving, inspection, and interim storage of the LTEP and associated hardware
- GSE preparation, ground crew training, and prelaunch checkout of the module

Office space for Lockheed personnel will be made available at the Lockheed facility on North Atlanta Avenue, Cocoa Beach. Figures 76 and 77, respectively, illustrate the KSC site locations and support facility layout.

Major LTEP activities at KSC will occur in the Manned Space Operations Building (MSOB). MSOB activities will include receiving-inspection, mating of LTEP Module with the Upper Stage adapters, fairings, etc. and complete systems checkout to verify integrated module operation. The entire integrated module will then be mated with the launch vehicle.

In addition to the MOSB, Launch Complex 37, and supply shipping and receiving, LTEP support may be required from the following additional KSC facilities:

- Radar Boresight Range (RFSTF)
- Hypergolic Test Building (HTB)
- Cryogenic Test Facility (CTF)

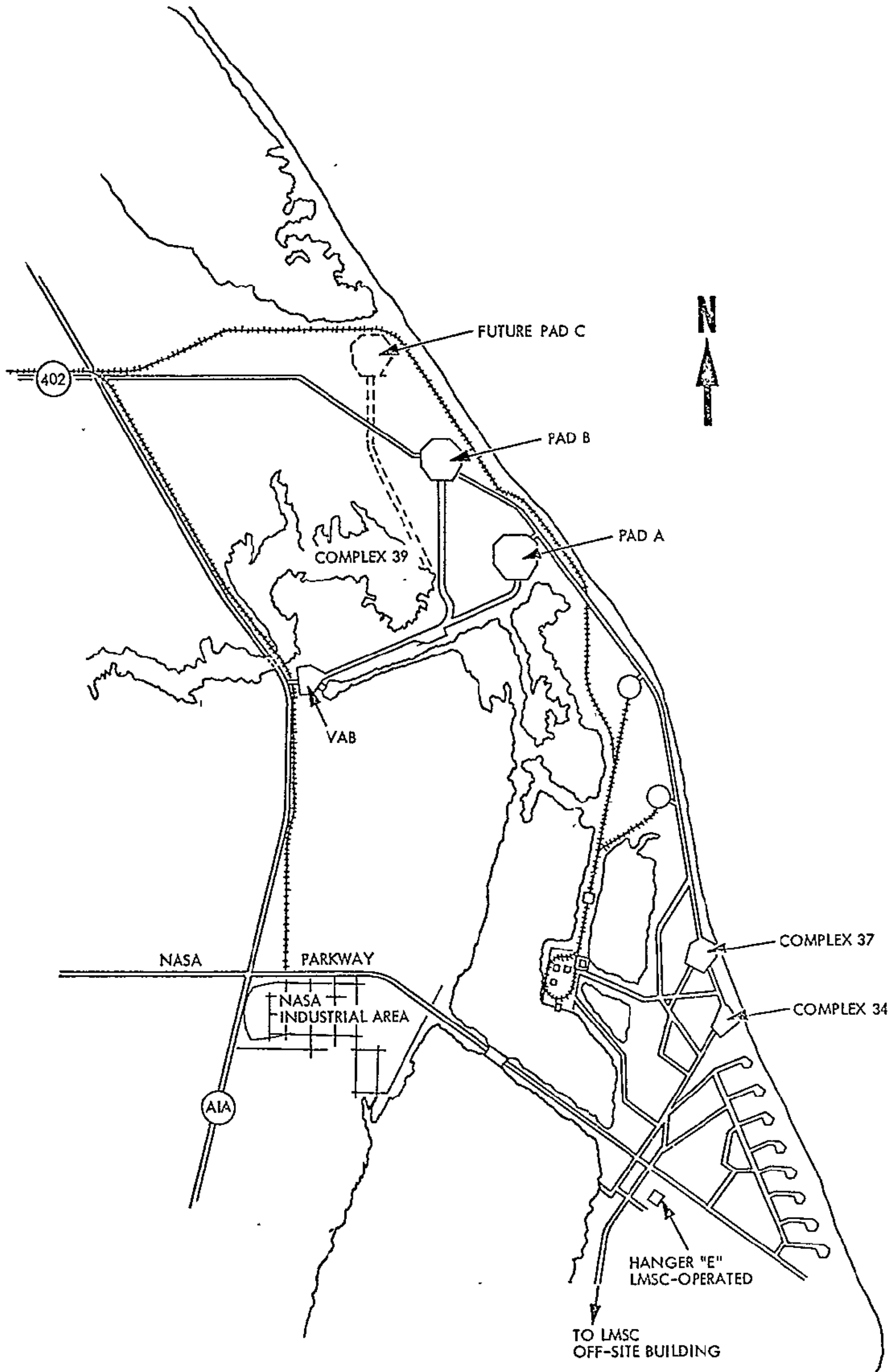

Fig. 76 Location Map of Kennedy Space Center

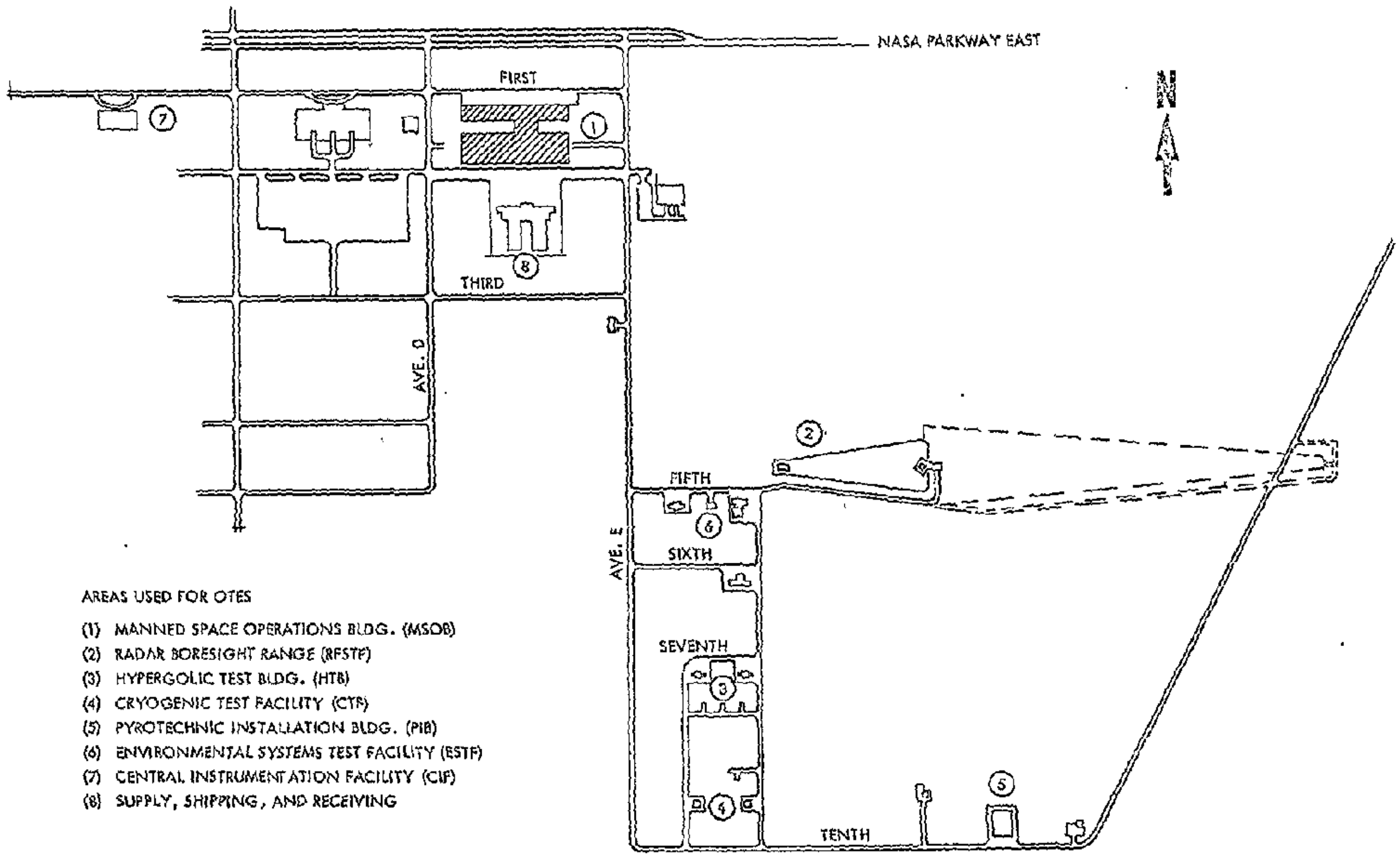

Fig. 77 LTEP Support Facilities at KSC

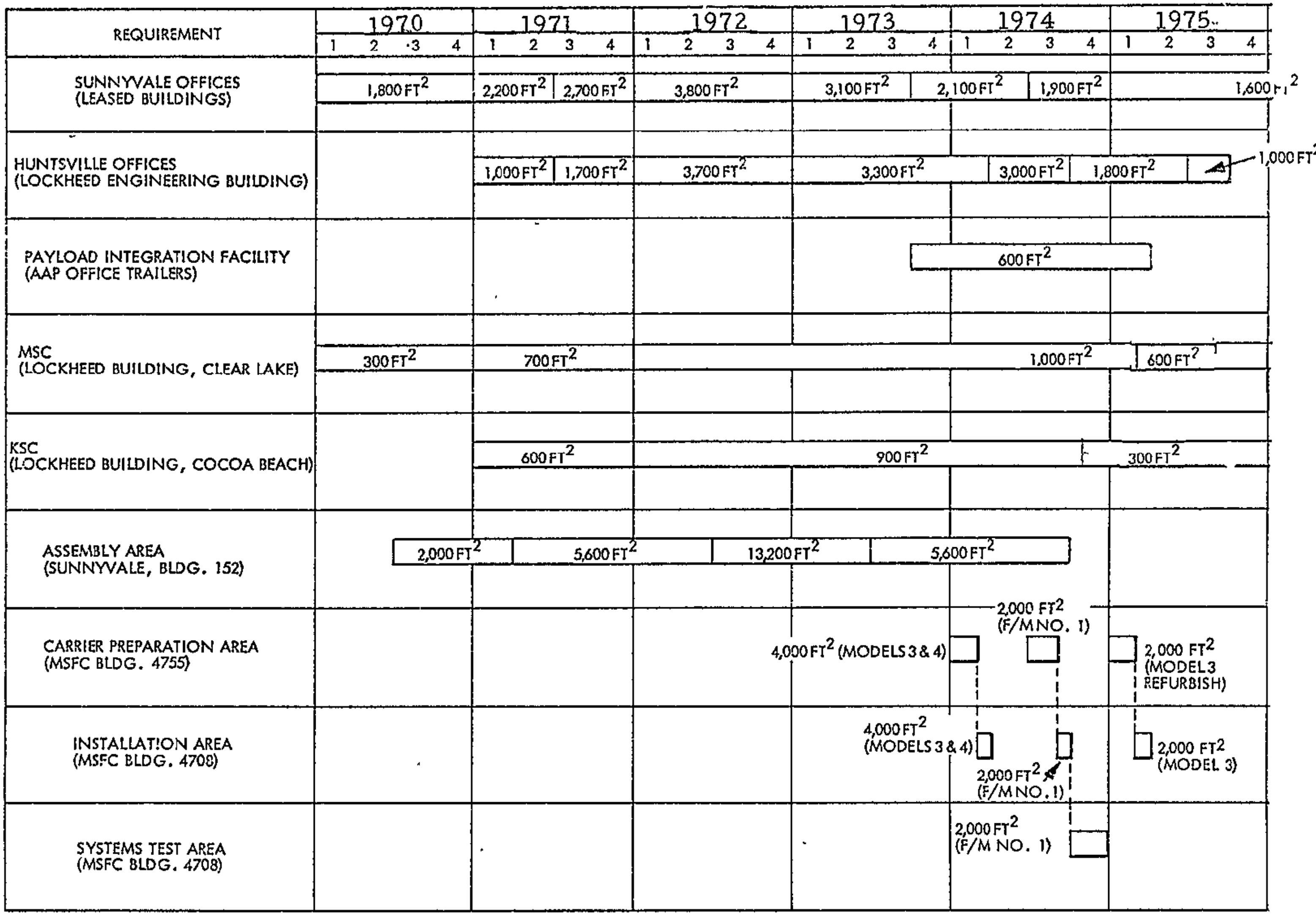

Fig. 78 Facilities Activation Schedule

- Pyrotechnic Installation Building (PIB)
- Environmental Systems Test Facility (ESTF)
- Central Instrumentation Facility (CIF)

Modification Requirements. Preliminary analysis of basic LTEP facility requirements indicates that no major modifications or new construction will be required beyond that already planned. Current planning indicates that the Sunnyvale Building 152 Assembly Area equipment access door will require widening from its present 12-ft width to accommodate LTEP hardware and tooling. Figure 78 summarizes the planned activation and utilization of facilities to support the LTEP Program.

5.4.4 Preliminary Test Plans

LTEP master test planning document is based on current NASA standards and practices relative to major system hardware qualification and acceptance testing. Consistent with the early conceptual study phase, this preliminary plan provides a guide to later development of a refined master test plan and establishes requirements for the test prototypes and test activities needed to verify launch and mission readiness for the LTEP Module in either the Cluster or Independent modes.

5.4.4.1 Scope. The preliminary test plan defines and describes the types of tests, test techniques, and assumed guidelines and constraints associated with the LTEP development activity. This plan outlines the major activities and interrelationships required for design verification, development, qualification, and acceptance testing of nonflight hardware and the prelaunch system tests and pad checkout of flight hardware. Hardware items at all levels of assembly from piece parts through the complete LTEP Module are included. The master schedule covers the period from the beginning of Phase B in early 1970 to the assumed launch data in 1975.

5.4.4.2 Guidelines. Ground rules for hardware and test requirement development assumed for the LTEP are summarized in the following subsections.

a. The LTEP Module's subsystems for all four optional modes are shown in Table 27. All optical subsystem electrical components will be contained in the electro-optical equipment compartments of the Telescope Assembly. The current AAP configuration ATM rack will be modified and simplified by deleting nine battery modules, unneeded signal and power leads, several un-needed electrical components and making several minor cable harness changes. Most electrical hardware will have been previously qualified in Apollo and/or post Apollo programs. Also deleted from the ATM rack will be the four outrigger supports: the top superstructure and two of the present four solar array wings. Added to the rack will be two solar array rotational devices and attachments for the telescope structure assembly and the Propulsion/Support Module (PSM).

b. <u>Test Activities</u>. One central test organization will be established; it will be responsible for all test planning, including coordination with the various design groups in establishment of integrated test program requirements and their dissemination in the form of test plans. All testing will be performed under the cognizance of this organization except for receiving inspection, manufacturing inprocess testing, and some prelaunch checkouts. This organization, however, will have the responsibility of reviewing all fixed procedures employed during the aforementioned activities and approving the original issue and any subsequent changes to those documents that deal specifically with the LTEP Program.

Test requirements in all categories emphasize testing at the highest practical level of hardware assembly. Integrated system testing, in most cases, will supersede component or subsystem level testing; Propulsion/Support Module subsystem components will have been previously qualified. Manned participation in the chamber during thermal vacuum testing at MSC is assumed. Trained operators and/or test technicians will perform the initial debugging runs; astronauts will assist in the qualification and flight-hardware demonstrations as a part of their familiarization training.

Ground support equipment (GSE), particularly for use with electrical testing, is subject to the same acceptance test philosophy as the flight hardware in cases where it interfaces directly with the flight hardware. GSE at the system level, such as a system test complex, is validated with comprehensive simulators by the using test organization. Use of prototype and flight hardware for checkout of the test equipment will be kept to an absolute minimum.

Whenever practical, development and qualification testing will use flight prototype hardware. This approach does not prohibit breadboard development testing before flight prototype hardware is available, but requires that planning include its use at the earliest possible point in the test program to assure the identity of what is tested and what is flown. Each functional black box will have certified evidence of qualification by analysis and test. In the case of rack components, certification is assumed to be available from AAP. Qualification testing and/or certification is required at each successive level of assembly up to and including the integrated LTEP Module. Reliability data requirements will be satisfied through development, qualification, and acceptance test data from LTEP and other programs. In special cases, where the quantity or quality of existing test data are inadequate, additional reliability testing will be conducted.

Government furnished equipment (GFE) will be considered qualified and acceptance-tested at the original contractor's facility. Receiving inspection will consist primarily of identification and damage checks. Critical electronic hardware, however, will be subjected to power application tests to verify polarity, phasing, and internal routing, and to check for gross defects such as short circuits or broken wires. Manufacturing inprocess testing is limited to those tests necessary to verify the integrity of the fabrication and assembly provess. Inprocess tests supplement the final acceptance test of the flight hardware when the final test cannot adequately verify functions below the top assembly level. Environmental (thermal-vacuum) testing of flight prototype hardware at the system level is essentially an integrated functional test of the flight article. Integrated system testing of the assembled LTEP Module consists of a mission sequence test at ambient conditions and a repeat of this test under simulated thermal vacuum environmental conditions. Electromagnetic interference (EMI) compatibility of the integrated system may be evaluated at MSC before and/or after the thermal-vacuum tests.

Flight or flight prototype hardware is used when possible for Cluster mode mechanical and electrical compatibility testing. Master tools and mockups will be used only when the flight level hardware is not available. Prelaunch checkout is conducted at the integrated system level. Checkout procedures developed during operations will be employed during integrated systems test. Correction of integrated test failures is made by replacement of the malfunctioning black box.

5.4.4.3 Test Control Documentation. Documentation controls are applied in varying degrees of sophistication depending on the test category. In general, they progress in depth of detail and rigidity of control from breadboard testing.

a. Test Documents. Test documents include the Master Test Specification, Subsystem Test Specification, Component Test Specification and Test Procedures.

Master Test Specification. This specification is subordinate to, and derived directly from the LTEP Module system specification. In outline format, it lists the several levels of tests to be performed (experimental, developmental) at each system level (integrated system, spacecraft system, subsystem assembly, and component) and provides the performance limits to be demonstrated in each applicable test. The established limits on test levels for each parameter will be determined jointly with NASA test specialists and will receive written NASA certification before the qualification program is initiated. The specification will be drafted by systems engineers in cooperation with the design group. It will serve as a reference and a guide in the preparation of all lower-level test specifications and procedures and will govern the sequence in which the tests are conducted.

Subsystem Test Specification. Each subsystem test program is covered by a separate specification document derived from, and subordinate to, the master test specification. In addition to reiterating the performance limits, the subsystem specification defines the overall test objective and general approach for the subsystem as a whole and for the major assemblies (if tested separately). It defines the locations and type of test instrumentation, the expected scale range for test readings, and the amount and general format of data records and test reports.

Component Test Specification. In those few cases in the LTEP test program where components will be tested individually (because of prior qualification of ATM and/or other Apollo subsystems), two types of component/test specifications apply. One type, applicable to newly developed or significantly modified purchased components, is covered by an LMSC Design Control Drawing (DCD) and a detailed Acceptance Test Specification (ATS). The other type, applicable to off-the-shelf purchased components for which qualification certification exists, is covered by Specification Control Drawings (SCD) which describe the principal feztures and refer to the appropriate test specification, i.e., either an LMSC-approved vendor specification or an LMSC-generated specification.

Test Procedures. Test procedures written by test engineers, reiterate the purpose of the test: the detailed performance limits to be demonstrated and the data requirements, the specific instrumentation and test equipment, how it is to be set up, procedures to be followed, the frequency of data logging, and other instructions and guides. Test procedures are reviewed by, and subject to, written approval of System Engineering.

b. Test Support Documentation. Some test control documents are not as formal as a specification, but rather serve as necessary documentation to the overall control and support of the test program. These are described below.

Log Book. This is a summary document, initiated by Quality Engineering, which provides a complete history of each component, assembly, and subsystem. This type of document has been in effective use by LMSC for years and is currently used as the hardware and operational control document for space systems.

Calibration and Certification. Test equipment is calibrated and certified to ensure test integrity. The proficiency of test personnel is also re-examined at regular intervals. Quality Assurance audits the organization records and certification status of all test equipment and personnel. Test and support equipment is validated to approved procedures on initial installation and use. Periodic recalibration requirements are determined and so noted on the equipment by application of a coded placard indicating the necessary recalibration date. The using organization maintains records of all equipment requiring this maintenance and rotates equipment as necessary. Quality Assurance personnel provide surveillance of records and equipment to ensure that only calibrated and certified equipment is used. Personnel assigned to critical operations, such as thermal-control surface preparation and manned-system testing, will receive special training and certification. The using organizations maintain certification records and periodically recertify personnel. Quality Assurance personnel audit these records and verify certification.

FACI/DD 250. This is the presentation and delivery of completed equipment for for acceptance, and is the responsibility of the Quality Assurance organization. All affected organizations are required to provide support to the Configuration Management Office for the First Article Certification Inspection (FACI) evaluation and to provide all background and engineering records on actions taken. Flight worthiness of the end-item hardware is certified as part of this action.

Qualification Certification. Qualification is required of all flight hardware items. When qualification testing is required to determine design acceptability, test procedures developed by the test organization and approved by engineering are witnessed and verified by Quality Assurance. The Reliability organization prepares the qualification certificates and maintains the program qualification records.

Failed Equipment Data Report (FEDR). The FEDR system was devised to accomplish, with minimum paperwork, the maximum dissemination of information on failed components or assemblies and the redesign correction of any trend or classification of failure on like or similar systems. It is both an informational and redesign tool and serves an additional function of ensuring good shop practices by reporting all anomalies on components or assemblies.

5.4.4.4 Tests and Test Events. The following test planning is identified:

a. Experimental Testing. Experimental testing may be compared to development testing except that test hardware has not progressed to the prototype phase. They are used to prove concept and feasibility of a general design rather than to determine if there is fault with a specific design.

   Typical of experimental testing, the following conceptual hardware items will be tested to demonstrate feasibility:

   - Protechnic locking device for extended telescope body position
   - Sun Shield Sensors – actuation control system
   - Alternate Telescope Body Structures – Strength and Deflection Testing
     a. Skin-Stringers
     b. Skin-Ring
     c. Honeycomb Sandwich

b. Development Testing. These tests identify design weaknesses, establish performance characteristics, and evaluate areas of potential performance degradation under simulated mission environmental conditions.

   - Tests of thermal distortion of telescope assembly
   - Launch loading and protection of quartz spacer rods
   - Structural load test of telescope assembly
     – load versus deflection
     – tube buckling characteristics
     – with and without differential thermal

- Ballast platform extension system
- Telescope extension system
  - screw jacks
  - manual override
  - position stops and erection alignment
- Propulsion/ACS
  - hot fire of breadboard (including previously developed components)
- Solar array single-axis rotational device
- Free float positioner device if magnetic suspension is used.

c. Receiving Inspection and Test. Receiving inspection, analysis, and testing will be conducted by Quality Assurance on all material and piece parts procured and stocked. The quality requirements are dictated by the current contracts, purchase orders, schedules, process controls, and prior source inspection and tests. All items are identified to reflect results of inspections and tests performed and final disposition. Data packages are prepared for part control and end-item acceptance. These data become an integral part of the hardware log book at the next assembly level and are used for reference as required at any point in the test program.

d. Manufacturing or Inprocess Testing. Inprocess testing is the sequence of activity which takes place during fabrication and assembly of end-item hardware and GSE. The Manufacturing Engineering organization performs this activity in accordance with Manufacturing Test Procedures approved by Engineering and monitored by Quality Assurance. For end-item hardware at the black-box level, inprocess testing ends with the acceptance test of the finished unit. For manufactured or modified GSE, the final inprocess testing is generally the acceptance of the equipment at the console level. Typical examples of inprocess tests are:

- Alignment checks and functional operation of extension, erection, are powered mechanisms
- Electrical and electronic circuit, high potential, and continuity tests
- Major section testing of structure before final mating of the sections
- Qualitative tests of the assembled LTEP to determine conformity to design requirement, installation integrity, and readiness for system test

e. AGE and GSE Testing. AGE and GSE must be tested and certified prior to use against any flight system. For certification, the AGE and GSE will be tested against a procedure rather than building checkout equipment.

The following tests are required as applicable, but are not to be construed as limiting:

- Visual and Mechanical Inspection
- Handling and Transportation GSE Proof Tests
- Fluid Proof Tests
- Environmental Tests
- EMI Testing
- Interface Verification Testing

f. Subsystem Installation and Compatibility Checkout. All subsystems and other GFE received are inspected for identification and damage for compliance with applicable documentation and proper gross functioning requirements for checkout, servicing, storage, calibration, and installation of each subsystem. Each subsystem is received and assembled into an LTEP qualification unit in a functional configuration. Tests are conducted to establish that compatibility exists between the subsystem and its support equipment. The subsystem/datasystem interface is established and verified.

g. Qualification Testing. Qualification tests demonstrate the capability of hardware not previously qualified to meet the requirements established. Tests are designed to provide a high level of confidence so that all items of hardware will survive the expected mission environment and will perform successfully. Test articles used for qualification will be manufactured by the same method and to the same tolerances as the flight hardware. Qualification testing of components and subsystems is at the highest level of assembly consistent with previous development testing experience and applicable past flight performance.

Qualification testing is applicable to flight prototype hardware only. The qualification overstress percentage levels of 10 to 30 percent, as applied to specific test conditions, will be specifically defined in the hardware specifications. Typical areas of concern, other than the standard techniques of structural load application and proof-pressure testing, are as follows:

- Temperature extremes in excess of design operating envelopes
- Energy input levels in excess of boost phase environment for vibration, acoustic, and acceleration testing
- Simulated solar radiation levels in excess of design operating envelopes for thermally controlled systems

- Input voltage and current level extremes in excess of design limits for critical electrical equipment
- Application of design limit test conditions for times in excess of design requirements (vibration, pressure, current limiters, etc.)
- Exposure to radiation levels in excess of design limits for radiation-sensitive equipment

h. Integrated System Testing. Integrated system testing is a simulation of the mission profile as closely as the ambient environment permits. A simulated countdown test is performed to verify that the LTEP Module and the associated support equipment are properly conditioned electrically and mechanically for the simulated flight. The LTEP is then placed in the prelaunch mode, and a simulated flight is performed. The test sequence proceeds from prelaunch through launch, ascent (rendezvous and docking), orbital transfer, activation, operations, deactivation, and storage, with certain functions simulated to present as realistic a flight sequence as possible. Performance is evaluated through the airborne telemetry data system. A crew is used during orbit simulation to pattern the astronaut activity and obtain maximum utilization of on-board checkout systems for stimulation and response. Vehicle interrogation and data readout modes are exercised. The test ends with an evaluation of normal operations and backup modes. The data from this test are part of the basis for vehicle acceptance through the DD-250 format.

i. Mass Characteristics Test. Final testing for weight, CG, and moment of inertia is performed on both the thermal qualification unit and flight unit just before they are shipped to the thermal-vacuum facility. Data from this activity are used as verification of previous engineering calculation and provide certification for the weight statement input to launch and orbital operations. All flight hardware must either be installed or adequately simulated.

j. Environmental Test (Thermal Vacuum). The thermal qualification unit and the flight LTEP Module are both subjected to thermal-vacuum environment. The environmental level for this test is lower than the design limits or operating envelope for the hardware. The purpose of this test is to substantiate the math-thermal analytical model. In addition, any defects will be revealed which might have occurred in the fabrication, assembly, and other processes, such as marginal electrical connections, improper thermal-surface application or control, and system level defects or interactions that by their nature cannot be discovered in an ambient or static environment.

k. Anechoic Chamber Testing. Electromagnetic compatibility (EMC) tests are conducted in an anechoic chamber in conjunction with the final systems tests on the flight prototype configuration. Typical requirements of EMC testing are:

- The mission configuration is compatible within itself in all operating modes and flight sequences.

- A minimum safety margin of 6 db in voltage or current exists at all critical points within the vehicle and at the critical interfaces of the launched vehicle.

- The flight vehicle configuration is compatible with all anticipated electromagnetic environments.

Specific EMC requirements for the mission and flight as dictated by mission operations and hardware design will be contained in individual detailed test plans and specifications.

1. Prelaunch Tests. The launch-pad sequence follows the standard Apollo test plan consisting of premate checks, simulated flight, flight readiness test, and countdown demonstration tests. The LTEP special tests and confidence checks will be performed in a manner similar to that used for the ATM spar. The payload and the LTEP Module adapter are installed on the launch vehicle, and premate tests ascertain the compatibility of the two units with the launch complex GSE before the final mate. This phase also checks the communications systems. The combined readiness tests furnish the final all-up verification of space vehicle readiness. The simulated countdowns and flight operations ensure that the system will perform properly in the sequences planned for the mission.

5.4.4.5 Test Data and Reports. Formal test reports and other test documents (such as procedures) serve as a historical record of component or subsystem development and test. Test data, signed off by Quality Assurance, certify proper performance of the various checkouts and tasks assigned to the hardware by Engineering. Development test records will be maintained in Sunnyvale.

Reporting is required for all testing performed, and the information (data and reports) is stored and maintained in a test program data bank, with cross-referencing and indexing by flight, test category, and hardware identification. The information storage and retrieval techniques used are adaptable to computer application at a later date.

The qualification test report summarizes the results of qualification tests at all system levels. Raw data from qualification and acceptance testing are recorded on log sheets or magnetic tape during the test, and are retained for processing and record purposes. Onboard telemetry data, processed and analyzed, are used as the primary basis for LTEP acceptance, with hardline data for readout of test instrumentation. The data processing function is performed by the test organization and the data analysis function is performed primarily by the test organization, but in close conjunction with engineering personnel. At MSFC and KSC the RCA 110 and at MSC the ACE automatic checkout systems will be used for computerized data processing and analysis.

Test reports containing test results on a specific test or phase of testing will be periodically released. Some major milestones are:

- Completion of all development-level demonstration tests

- Completion of dynamic and static development testing of the LTEP structural prototype

- Completion of the LTEP engineering prototype thermal-vacuum test
- Completion of the integrated systems tests

5.4.4.6 Test Scheduling. The complete LTEP Module master schedule for testing is presented by Fig. 79. This schedule shows gross functions from which more detailed schedules can be produced in subsequent phases of program development. Phase C is primarily devoted to AGE/GSE and LTEP system design, mockup fabrication, and development model testing. Late in Phase C, an engineering handmade model is produced for further development tests. Six months later a structural test model and a thermal test model are fabricated to hard tooling for qualification testing.

The models are then shipped to P-E for integration of the optical subsystem prior to qualification test. These models, with optical system or mass equivalents, are to be mated to the rack at MSFC. The design integrity of these two flight prototype models is qualification tested at MSFC. The flight unit construction and assembly are initiated in 1972 - approximately 18 months after the start of development testing. This period provides time for design updating and improvement prior to flight model fabrication.

The flight model will be fabricated at LMSC-Sunnyvale, shipped to Perkin-Elmer in Connecticut for optics installation and checkout, and then moved to Huntsville for mating to the modified ATM rack and then it is instrumented and checked out. Following DD-250 at MSFC, the flight unit is shipped to MSC to undergo a manned thermal vacuum test for verification of flight worthiness. Following this test, the unit will be shipped to the Eastern Test Range to undergo prelaunch tests and countdown to launch in 1975.

5.4.5 Schedule Plan

The LTEP Preliminary Summary Schedule, Fig. 80 illustrates the salient features of the LTEP. In Phase B, the "model fabrication" refers to the metal partial mockups utilized during the "research span" for zero-gravity and neutral-buoyancy EVA simulation.

In Phase C, the Engineering development model needed by Perkin-Elmer to support optics subsystem development is shown being fabricated before and after the principal design freeze. The model fabrication in 1971 is essentially the LMSC engineering model and is complete approximately three months after the mirror is available. The period of "development test" includes mechanism design verifications and structural thermal testing of the engineering model, respectively.

Fabrication of primary tools used for major structural assemblies begins immediately after Phase D go-ahead. To facilitate this, principal tool production tool production orders are written in Phase C. After fabrication of the LMSC structural test model, which is the first tooled unit, the secondary tooling is incorporated in the third quarter. Subsequently, the completed tooling is utilized in fabrication of the two qualification prototypes.

The qualification program carries the structural and thermal units in parallel to provide maximum scheduling flexibility at the AAP Integration Facility. Upon completion of qualification, the thermal model is refurbished in Building 36 at MSC and shipped

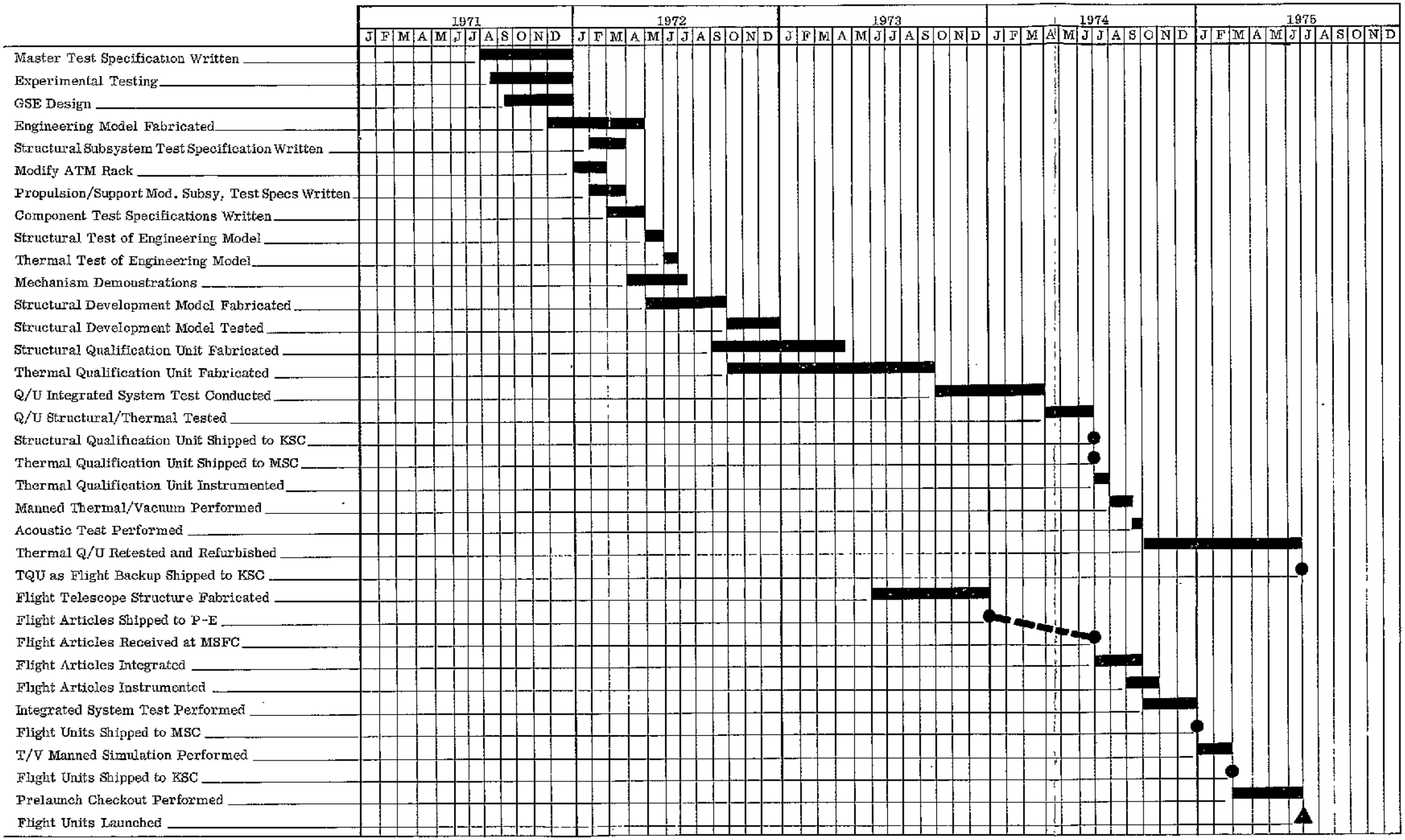

Fig. 79 LTEP Module Test Program Schedule

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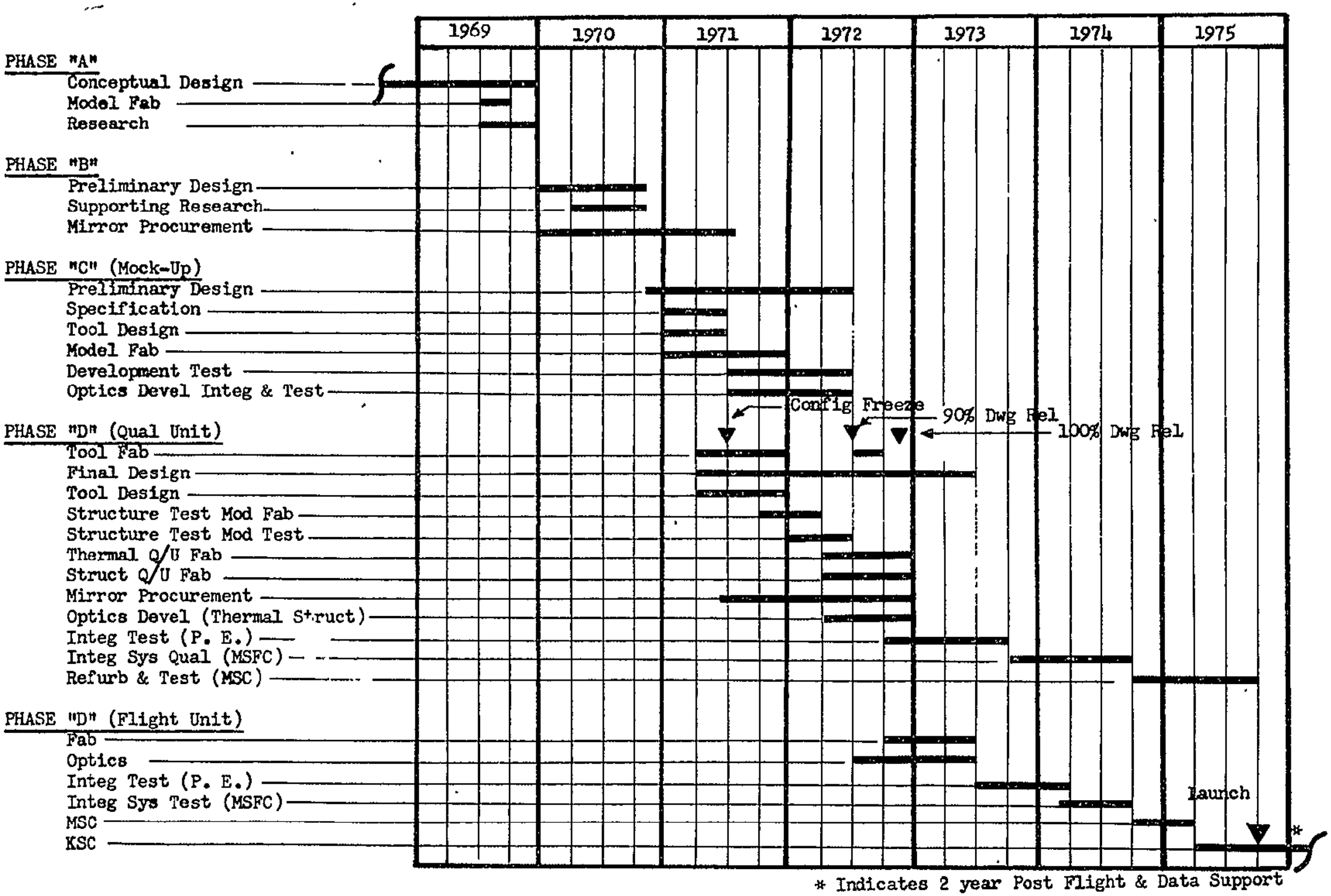

Fig. 80 Large Telescope Experiment Program (LTEP) Summary Schedule

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to KSC as a flight backup unit. The structural model, which is provided with a mockup mirror, is shipped to KSC for use as a ground crew trainer. The thermal model will already have served as a flight crew indoctrination model at MSC.

Flight article fabrication is started as late in the program as its nominal acceptance and checkout spans allow, to take maximum advantage of qualification testing experience. Procurement of the mirror is a pacing item and a nineteen (19) month lead time must be allowed. The mirror that is used in the thermal qualification unit will also be used as the flight article.

5.4.6 Cost Plan

Refer to Chapter 18 of Volume I for the discussion of the cost plan. Figures 81 through 84 are reproduced from this discussion.

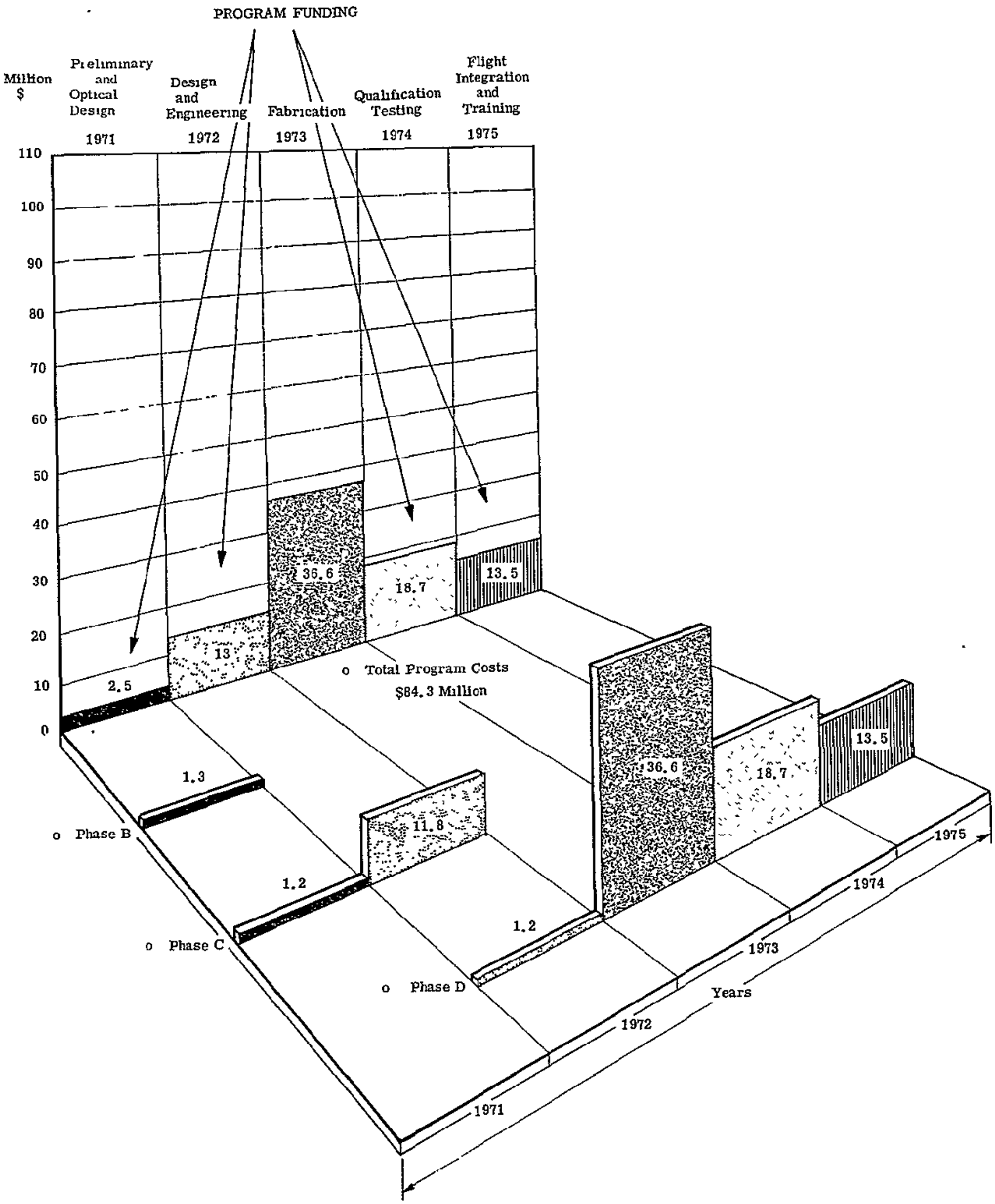

Figure 81. Funding Requirement for Sky Lab - LTEP

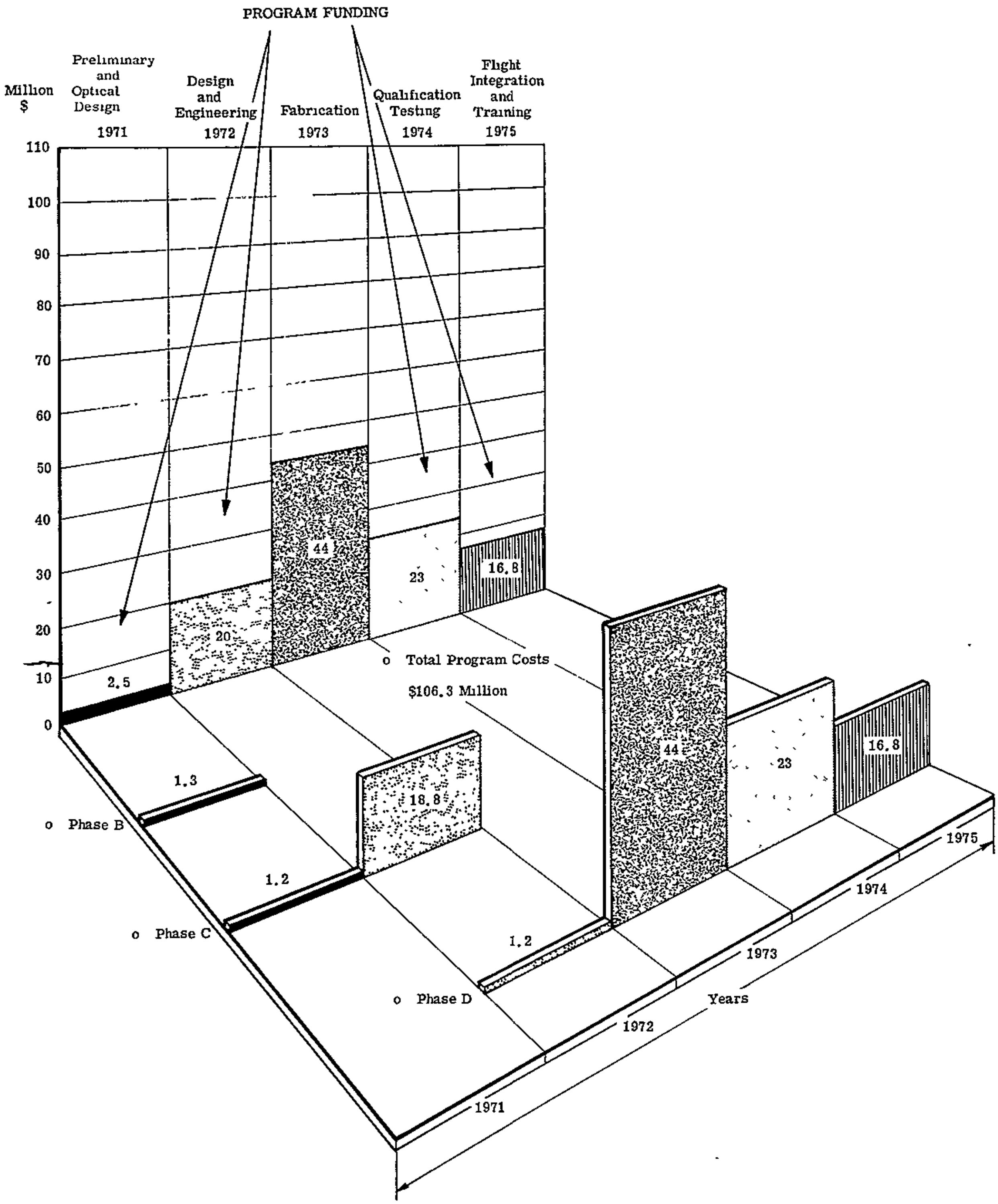

Figure 82. Funding Requirement for Titan IIIC

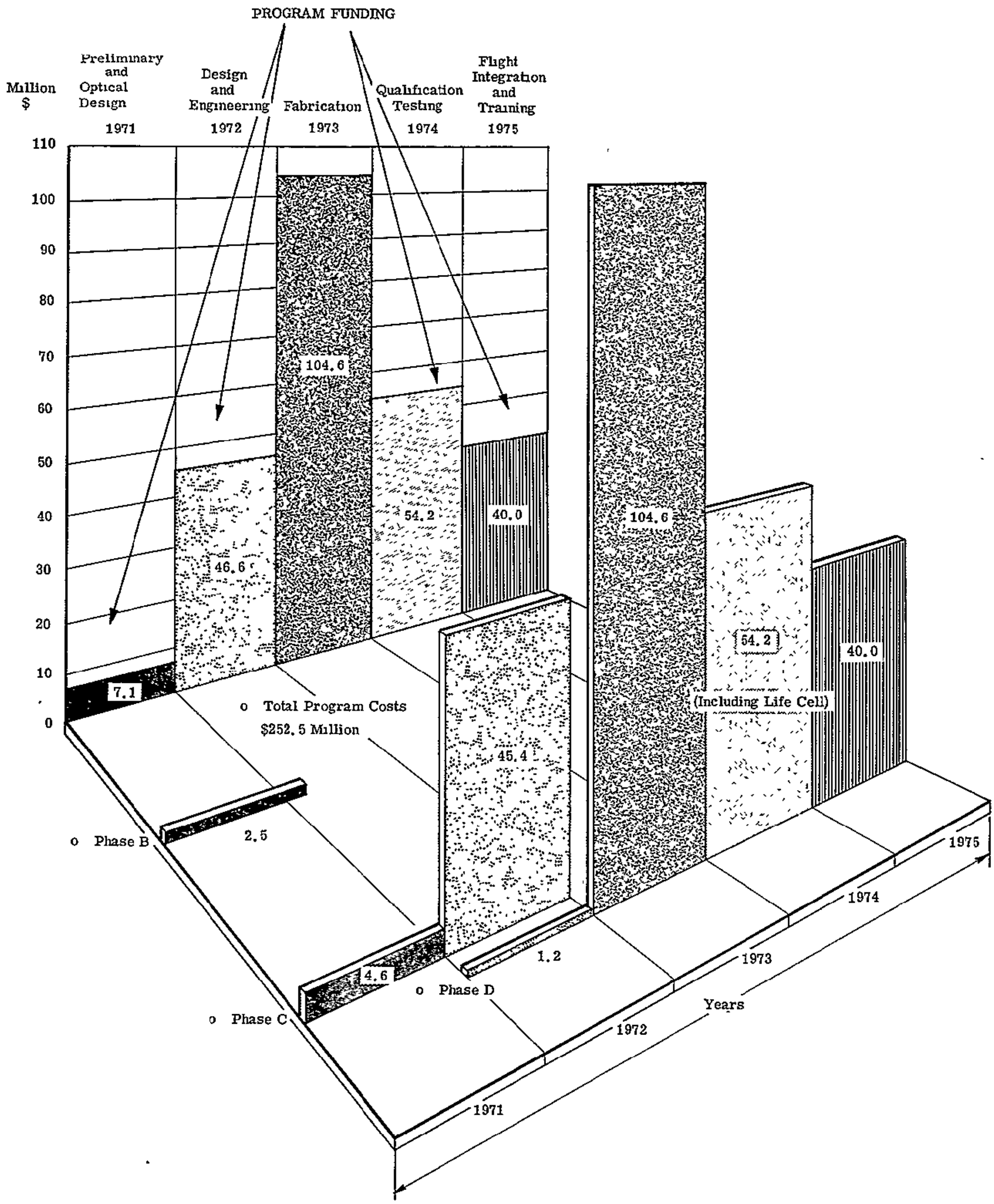

Figure 83. Funding Requirement for Saturn IB-LTEP (with Motel)

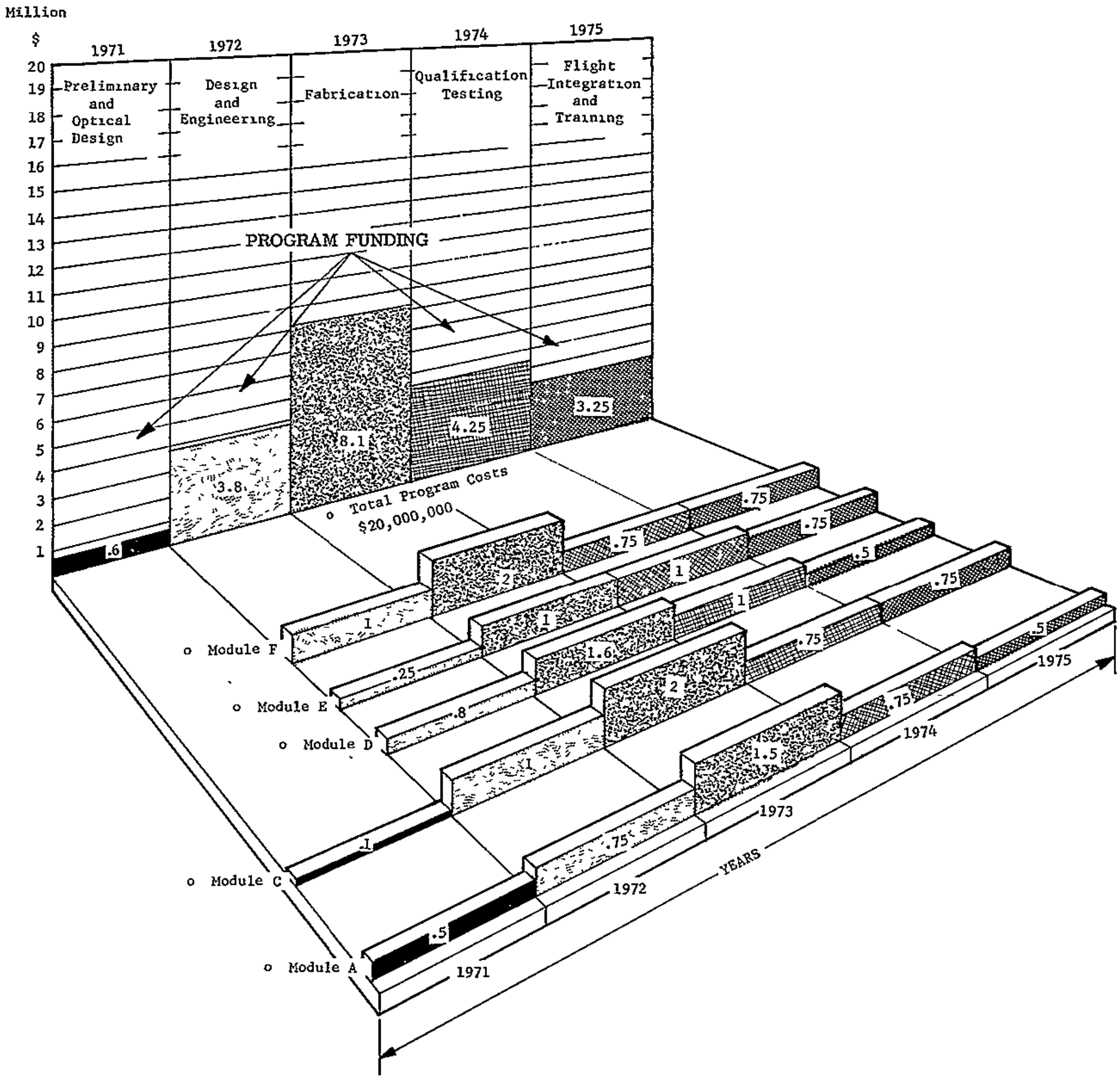

Figure 84. Funding Requirement for Experiment Modules

SECTION 6
SPACECRAFT RECOMMENDATIONS

Section 6

SPACECRAFT RECOMMENDATIONS

The LTEP study effort described in the preceding sections established the feasibility of implementing the recommended concept. Considerable additional analyses and supporting effort are required, of course, prior to initiation of final design and hardware development activities. These tasks are logical follow-on efforts to the conceptual studies accomplished under the OTES and LTEP projects. They could be performed as Research & Development (R&D) supporting technology or, preferably, as a portion of an integrated Phase B (and/or early Phase C) spacecraft support study program.

The primary recommended spacecraft tasks are delineated in the following paragraphs. No attempt has been made to list all spacecraft study and design tasks required prior to initiation of Phase C development. Those key study items, however, have been identified which constitute principal study areas and trade-off analyses required to be accomplished for an early implementation of the recommended large stellar telescope system.

6.1 MISSION PARAMETERS

A more detailed delineation of orbit parameters should be accomplished. This will include trade-off analyses and selection of the orbit decay makeup cycle, ascent profile for the specific mission mode, and illumination parameters for a two-year period from a particular launch date.

6.2 ASTRONAUT PARTICIPATION STUDIES

Because a 1974-75 flight date for an LTEP/ATM only allows a minimum span for flight crew support operations and crew systems equipment developments, it is recommended that the follow-on effort provide the following:

- Astronaut task/equipment analyses
- Astronaut operations time lines
- Conceptual designs and development planning for new crew systems equipment requirements, particularly task aids.
- Training plan, and training equipment conceptual designs and development planning to satisfy new requirements.

Two pacing items that should receive special emphasis are detailed momentum management analysis and plan as a function of the total mission flight profile and conceptual designs and design integration of the crew systems task and work aid equipment (transportation system) necessary to support the mirror segment replacement operation. The momentum management analysis and plan is properly a guidance and controls system function, but is an absolutely essential prerequisite to producing valid astronaut task/equipment and time line analyses.

6.3 SPACECRAFT STRUCTURE

Analysis should be made of the new structural interfaces imposed by the AAP Dry Workshop Cluster, the 3-section telescope and the screwjack conceptual designs. These and other areas require further preliminary design and system definition. It is proposed, therefore, that follow-on (Phase B) effort include the following definitive studies.

- Detailed study of ATM Rack structural modifications required for the LTEP.
- Detailed dimensional layouts of the LTEP telescope structure, including determination of structural misalignment tolerances.
- Further study of 3-section telescope details and detailed definition of screw-jack extensions subsystem.
- Detailed study of structural and functional subsystem interfaces between ATM Rack - AAP Dry Workshop Cluster and LTEP system.

In addition a loads analysis should be performed following accomplishment of these structural definition efforts.

6.4 SPACECRAFT SUBSYSTEMS

The propulsion subsystem components should be defined and specifications established for the operational parameters of the equipment. Location of these components should be specified and detailed tank sizing and propellant usage calculations accomplished.

It is recommended that the following five electrical subsystem items be considered for inclusion in any follow-on study of the LTEP system.

- Further investigation of AAP Cluster electrical componentry should be made to determine specific circuitry alterations required in reducing quantities of electrical components for the LTEP system.
- Evaluation of the AAP Cluster componentry (other than solar arrays and batteries) for life-times up to 24 months (specifications now are for 9 months); determination of critical failure modes and establishment of hardware redundancy in the "weakest" areas.

- Establishment of a preliminary design for a roll-out type solar array and tradeoff weight decrease obtained (versus ATM array) with other LTEP program parameters of cost, delivery, hardware confidence.
- Development of a preliminary design for a 360 deg-rotating mechanism for the ATM solar array and establishment of mechanical interfaces with the solar array and the ATM Rack supporting structure.
- Development of a preliminary design of a ±180 deg-rotation device for the OWS solar arrays utilizing previous "wet" workshop hardware where possible. Establishment of mechanical interfaces with the new Dry Workshop (SIVB) structure.

As primary tasks in extended Phase B study, the following guidance and control tasks are proposed:

- Obtain and analyze the data from recently completed NASA/MSFC simulation runs on the ATM control system.
- Determine by analysis and/or extrapolation of test data spectrums of amplitude versus frequency versus angular rate output of the CMG/PCS control loops as they are planned for the Dry Workshop Cluster.
- Superimpose analytically the moments of inertia of the LTEP telescope gimballed mass and determine effects upon ATM control system response.
- Investigate specifications, design details, and test data on the components of the ATM control system to determine capability for surviving a two-year or longer operating life. Identify "critical" components for consideration as redundant passive elements or as replacement spares.
- Develop a detailed functional schematic for the control subsystem in the LTEP Propulsion/Support Module to supplement the ATM control system in the Independent LTEP flight mode. Also, define the specific functional interfaces with the ATM system.

Because space-qualified hardware compatible with S-band operations with the MSFN are available for use in the LTEP Communications and Instrumentation subsystem, a large potential savings in LTEP development cost exists. However, considerably more proof is needed that these hardware elements are capable of operation for the two-year period of the LTEP system. It is recommended that a high-priority follow-on study task be initiated to: (a) investigate the designs and functional characteristics; (b) analyze previous test results and operating reports; (c) evaluate the probability of extended life operations in the LTEP system environment; and (d) recommend modifications to components or standby redundant installations to provide the two-year life capability in the subsystem. Also, establish follow-on study effort to further detail the LTEP communication subsystem and establish firm interfaces with the AAP Cluster.

6.5 THERMAL ANALYSIS

Follow-on thermal analysis should be performed to delineate operating temperatures with more exact definition of equipment locations and component thermal properties. The specific multi-layer insulation and Optical Surface Reflector (OSR) mounting arrangement should be determined. An increase in the number of nodes on the primary mirror is necessary to obtain a better definition of thermal gradients. Transient thermal analyses must be conducted to determine the effect of the sun cap actuation and effect of any incident solar energy. These studies would determine the limiting time that the sun cap could be left open.

6.6 RELIABILITY

Upon definition of the system and subsystem equipment and components, preliminary mean time before failure (MTBF) calculations can be made. Critical system elements (e.g., CMG s, electrical and communication equipment) should be examined to assure that the desired two year operating life can be obtained with the recommended configuration.

6.7 RESOURCES PLANNING

Following selection of the mode of implementation of the recommended configuration, further refinement can be accomplished on the resources planning documentation. In addition to further detailing of the technical, subsystem, facilities, test, schedule and cost plans, additional data should be generated in the form of a quality assurance plan, reliability plan, manufacturing plan, manpower plan, development test plan, personnel training plan, data plan, and related program documentation. This generation of detailed program plans will formulate the basis for final (Phase C/D) program accomplishment.

6.8 OUTGASSING AND PARTICLE CONTAMINATION STUDY

Extensive effort is recommended as a follow-on to effort initiated on potential outgassing considerations. This effort consists of follow-on analyses, special design concepts and a test program.

6.8.1 Follow-on Analyses

It is proposed that the following list of candidates be used in establishing studies for the anticipated Phase B of the LTEP program.

- Further study the layering of contaminants of varying densities in the telescope field-of-view and determine the degree of light refraction and star image scintillation.
- Determine potential chemical reactions of incident gases and other contaminants in the telescope cavity with the optical surfaces.

- Determine the urine solids content type and quantity vaporized overboard by the AAP Cluster and estimate its flow patterns in dispersal in the vicinity of the LTEP/Cluster.

- Determine quantitatively the kinds and amounts of solid exhaust and debris from pyrotechnic devices planned for AAP Cluster/LTEP operation and estimate dispersion patterns, deposition areas probable, and approximate deposition worstcase thickness.

- Carefully review all organic materials intended for use on the LTEP system and assess their vacuum characteristics. Determine their approximate outgassing products and rates.

- Investigate potential of modification to astronaut space suit covering to eliminate current flaking-off of fiberglass particles.

- Determine the approximate composition of the "trial" of contaminants behind the orbiting spacecraft/LTEP telescope and assess the viewing characteristics when the telescope LOS is pointed through this mass.

- Determine possible quantities of uncombined fuel or oxidizer which may be emitted from bi-propellant thrusters during typical thrusting or dormant (leakage) cycle. Estimate the characteristic of dispersion in the vacuum near the LTEP/Cluster, both in the thrusting mode and the non-thrusting mode (latter for leakage only).

- Perform analysis of astronaut PLSS and space-suit emissions and probable effect on close-proximity to primary mirror and at end of telescope.

- Perform quantitative analysis on the effects of various contaminants on externally mounted solar arrays, sensor lenses, antenna surfaces, and thermal control surfaces. Particular emphasis should be placed on corrosive particles or liquids such as uncombined propellants or urine solids with water vapor.

- Determine by analysis and/or test the equilibrium condition of water vapor on simulated cold-plate telescope tube interior and adjacent optical surfaces. Assess preferential deposition of particles.

- Perform quantitative analysis of the effect on thermal characteristics and thermal balances within the telescope tube as a result of water vapor condensation or ice crystals formation.

6.8.2 Special Design Concepts

Two specific areas have been identified for possible further design effort in the near future. On the basis that condensation of vapors upon or deposition of particles upon the primary mirror surface is perhaps the most serious problem confronting the implementation of the LTEP system; and presuming that no reasonable external control will reduce the contaminants to a reasonable level tolerable to the mirror, it is proposed that:

a. Study be initiated to conceptually develop a cold-plate "trap" that can be installed in the telescope cavity in the vicinity of the critical optical surfaces (multiple units possible). This device would attract and hold all contaminants which came within the volume surrounding the optical surface and would then provide a "cleaning" action for particles which, by nature of velocity and mass, had deposited initially on the optical surface. Alternatively a source of pure gas might be utilized to impart a velocity to contaminant particles effectively "blowing" away diffusive materials. Such methods for periodic cleaning would be investigated.

b. A corollary study be initiated, using the same principle, to conceptually develop a device which could be carried by the astronaut in EVA and either automatically collect suit and PLSS emissions or could be manipulated by the astronaut in cleaning the primary mirror after close-proximity inspection (not touching the surface).

Both of the devices could be used in conjunction with vaporizing processes which could potentially be implemented periodically by automatic heating of the optical surfaces and thereby impart energy to previously deposited molecules, essentially driving them away from the optical surfaces and toward the cold-plate collector.

6.8.3 Test Programs

Specific test programs that could be initiated with current facilities should be considered for early Phase B effort. Among these could be the following two proposed analysis/test efforts.

a. A specific study and testing program to determine the deposition products on various LTEP critical surfaces and effects of bi-propellant thrusters, one of the main contaminant sources in the LTEP system.

   1. Calculate the thruster outputs.

   2. Calculate the plume (computer program).

   3. Calculate the plume impingement and flux at various critical surfaces (computer program).

   4. Determine the sticking coefficients (capture characteristics of the various optical surfaces).

   5. Determine surface deposition (by actual test of models).

   6. Determine equivalent transmissability losses of surfaces for various wavelengths of energy (UV/visible/IR).

b. An actual test of scattering, refraction, absorption, etc., of the LTEP environment utilizing various gases and particles injected into a vacuum chamber through which light beams of varying intensity would be passed. LMSC has a Solar Illumination Simulation Facility which creates, within a fixed test volume, an excellent approximation of the photometric environment as found in space. This facility could be used for such a test.

Section 7

REFERENCES

The following documents and publications were utilized in the performance of the LTEP study and compilation of study program results.

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12. Marshall, K. N., Breuch, R. A., "Optical Solar Reflector: A Highly Stable Low α_S/ϵ Spacecraft Thermal Control Surface", Journal of Spacecraft and Rockets, Vol. 5, No. 9, September 1968, pp. 1051-1056.

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20. NASA/MSFC document, ATM Weights and Moments - R-P&VE-VAW Program WP 04A, Ron Scott, MSFC, dated 3 March 1969.

21. NASA/MSFC Technical Memorandum X-53834, Stabilization and Control of the Apollo Telescope Mount, by Bill Chubb, dated 6 May 1969.

22. NASA/MSFC document, Saturn V Workshop - Program Definition Study - Technical Considerations, dated 7 July 1969.

23. NASA/OSSA, Launch Vehicle Estimating Factors, dated January 1969.

24. Perkin-Elmer Report No. 8900, Optical Technology Apollo Extension System (OTES) - Phase A Study, dated October 1967.

25. Royal Aircraft Establishment Report, TR 66290, Determination of Gas Flow Parameters from Propane Attitude Control Jets, and Their Effect on Satellite Optical Sensors and Telescopes, dated September 1966.

26. "Optical Environment in Gemini Space Flights", by E. P. Nuy, W. F. Huck, University of Minnesota, Science, Vol. 158, dated 15 July 1969, pp. 297 through 299.

27. "Optical Environment in Gemini Space Flights", by S. M. Silverman (Air Force Cambridge Research Labs, Bedford, Mass.) and J. W. F. Lloyd (Northeastern University), Science, Vol. 157, dated 25 August 1967.

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Appendix A

INFLUENCE OF OUTGASSING AND OTHER EMISSIONS ON THE LTEP OPTICAL SYSTEM AND SUPPORTING SUBSYSTEMS

A.1 OBJECTIVE

The primary goal of the subject supporting analysis was to establish the sources and fluxes of outgassing products and other contaminant emissions in the LTEP system (earth-orbiting, 2-meter telescope), so as to estimate the effects on LTEP optical viewing of stellar light sources of 12th magnitude and lesser intensities, and to establish means of avoiding or controlling the contaminants. The effects of contaminants upon other critical surfaces such as sensor lenses, thermal-control surfaces, solar cells, and antenna surfaces of the supporting subsystems were also of objective interest.

A.2 SCOPE

The study covered investigation and analysis of the effects of "outgassing" and other contaminants on various elements of the LTEP system but primarily the optical subsystem, and methods of controlling these effects. It comprised these elements:

a. Establishment of the quantities of emission versus time of various gases, liquids, and solids emitted from the system in both the AAP Cluster-attached and the Independent operating modes.

b. Examination of the dispersion characteristics of the molecules or particles around and within the LTEP telescope tube.

c. Estimation of the degree of actual deposition of molecules on surfaces.

d. Estimation of the number of molecules or particles in the field-of-view of the telescope, primarily external to the tube where light-scattering of sunlight would occur.

e. Examination, in qualitative terms, of the effects of the estimated contaminant fluxes on surface degradation and starlight attenuation or dilution with background illumination.

f. Determination of means for reducing contaminant fluxes and protecting system elements.

Because stellar-field viewing is more difficult in the daylight phase of an orbit (because of the higher background illumination due to sunlight), primary attention was devoted to conditions where the LTEP system is sun-illuminated. (Telescopes of the LTEP size would not normally suffer much viewing degradation with night-sky noise at magnitude 12 viewing.) Because detail analyses were not possible within the limits of the study subtask, only qualitative data have been derived in most cases. Follow-on analyses and/or testing are recommended (Section A. 7). The conclusions drawn are considered valid for conceptual design and establishment of preliminary interface requirements.

Except for comparative purposes, other influences on optical viewing (such as background illumination by earth-atmosphere) were not considered in this study. The effect of the LTEP system emissions on the various subsystems (antenna reflectors, solar arrays, star sensor, and thermal control surfaces) was generally assessed. Primary study emphasis was placed on analysis of the effects on the optical subsystem.

A.3 BACKGROUND

The major advantage of an earth-orbiting, stellar-pointing telescope system is the elimination of much of the distorting atmosphere between the telescope and the star field. With the advent of space telescopes which are expected to "see" 12th to 18th magnitude stars and operate for 2 to 10 years in space, it is necessary to analyze meticulously the effects of all potential gases, fluids, and solid particles upon the optical viewing field and upon optical surface degradation.

The expected increase in the ratio of starlight intensity to background light intensity can be degraded by local conditions in and around the orbiting telescope. Emission of contaminants from the spacecraft/telescope can result in one of two conditions:

a. The molecules or particles will enter the field-of-view or viewing tunnel of the telescope and cause light scattering, absorption, or refraction of starlight energy received and will increase background illuminance by sunlight impact on the molecules/particles external to the sun-shielded telescope tube.

b. Molecules or particles will impinge on optical surfaces and cause mechanical surface degradation, chemical reaction, or coating of the surface.

A number of documents have been prepared theorizing on the following:

a. The characteristics of the earth's atmosphere and its molecular and dust-particle content at various altitudes and the degree of background illumination resulting from direct sunlight and albedo impinging on the gases and particles.

b. The probability of sputtering damage (displacement of atoms or molecules from a solid surface by impact of high-velocity gases or particles) to orbiting spacecraft (at the spacecraft orbiting velocity).

c. The change in UV, IR, and visible light rays as a result of passing through "clouds" and other particle fluxes and the resultant background illumination created by visible light scattering.

Although potentially affecting the efficiency of the LTEP system, study of these phenomena has not be included and are considered beyond the scope of this "outgassing" concept study. Conversely, all available data pertinent to spacecraft emission of gases, fluids, or particles have been reviewed and potential effects of these effluvia on the LTEP optical subsystem have been analyzed.

A.4 SUMMARY

A cursory analysis was made of sources of contaminants (emissions) in the LTEP system which would degrade optical viewing of stellar targets by the 2-meter orbiting telescope. Also, the deteriorating effects on sensor lenses, thermal-control surfaces, antenna surfaces, and solar arrays were considered. The contaminant sources include:

- Propulsion device exhaust products
- Material outgassing (volatilization, pyrolytic breakdown, sublimation)
- Pyrotechnic device discharge
- Man-compartment gases – leakage and venting
- Residual dirt particles
- Dislodgment of ablative materials
- Expellants from experiments
- Ullage venting of propellants and pressurants
- Urine venting
- Astronaut shut and PLSS emissions (for EVA)
- Battery venting

The contaminant types and emission rates were determined and the characteristics of dispersion in the vicinity of the orbiting spacecraft/telescope were inspected. The elements comprising the emissions were molecules or particles of:

H_2O	CO	N_2H_4 (uncombined fuel molecules)
O_2	H_2	Urine solids
N_2	N_2O_4	Dust particles
CO_2	$(CH_3)_2N_2H_2$ and	Outgassed volatiles or organic polymers

The contaminant fluxes in the telescope FOV and the potential amounts entering the telescope tube (optical-surface cavity) were estimeted. The following general phenomena were reviewed regarding the relative effect on optical-viewing capability:

- Sunlight scattering
- Absorption of light
- Gas molecule reactionon surfaces
- Refraction and scintillation
- Sublimation
- Chemical reactions with optics
- Surface sputtering
- Condensation of gases

The degree of contaminant effects were determined and summarized in degradation parameters such as background illuminationor deterioration of optical surfaces.

Conclusions are presented in Section A. 6 of this appendix. These conclusions include lists of recommended approaches in selection of materials and determination of telescope/spacecraft design and operating sequences. Recommendations for follow-on analytical and/or testing effort are discussed in Section A. 7.

A. 5 RESULTS OF THE STUDY

Data representing the results of information collection and review, analysis, and determination of potential effects of contaminants upon the LTEP system are presented in the sub-sections listed following:

- Mission configuration and orbit orientation
- Telescope optical features
- Phenomena of optical degradation
- Exhaust products from thrusters
- Outgassing and contaminant dumping and venting
- Movement of contaminants around and within the telescope
- Effects of outgassing and other emissions on LTEP

Section A. 6 provides specific conclusions regarding the recommended configuration, preferred operating modes, and material selections required to obtain maximum protection from optical viewing degradation.

A. 5. 1 LTEP Mission Configuration and Orbit Orientation

The LTEP system has application to Independent, Cluster-attached, or space station-attached missions. Figure A-1 illustrates the LTEP module (ATM Rack, ATM Solar Arrays, Propulsion/Support Module, and Telescope) attached to the AAP Dry Workshop

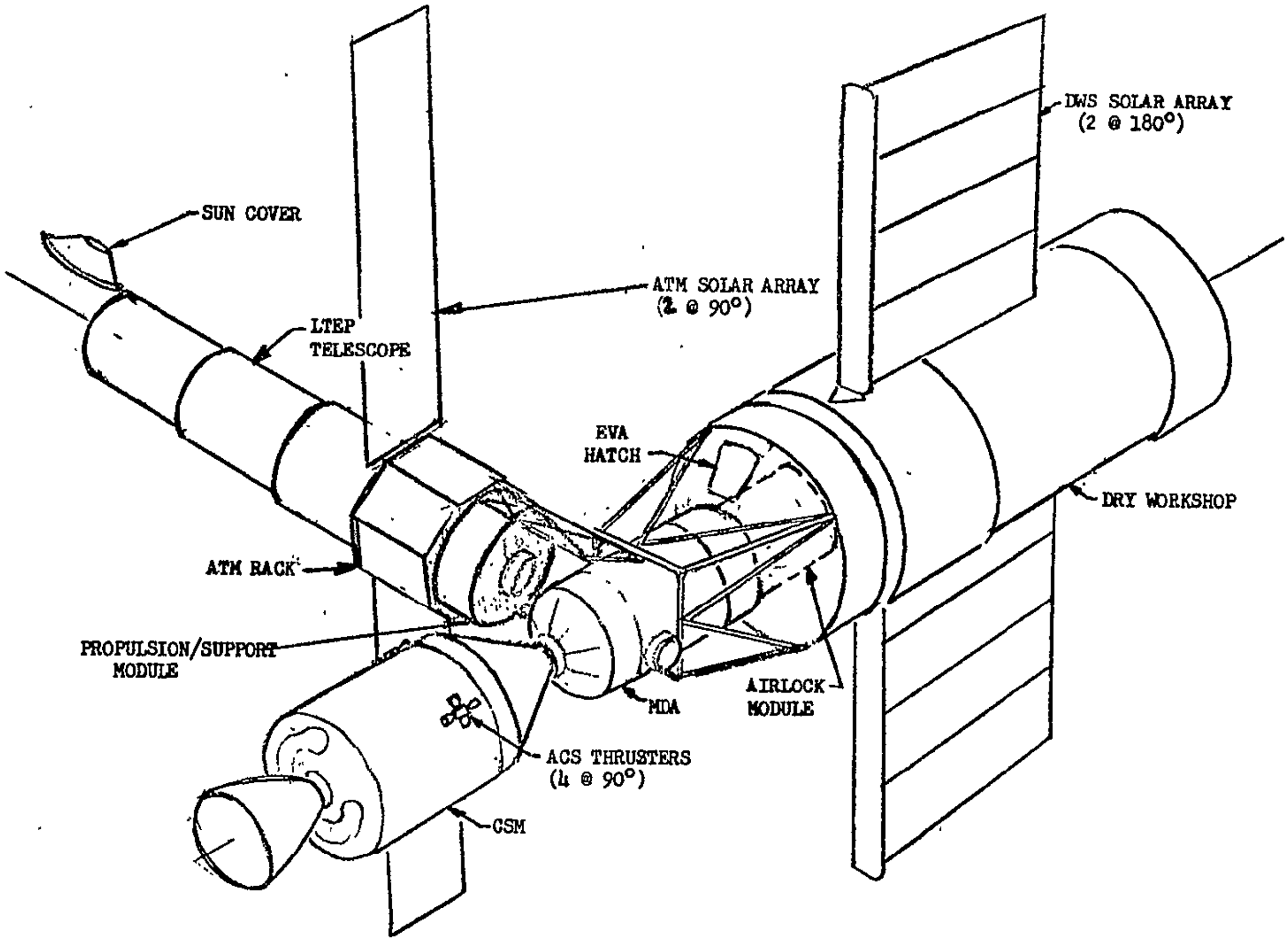

Fig. A-1 Dry Workshop Cluster and LTEP

Cluster (i.e., the baseline concept, the SWS-II LTEP). The space station-attached configuration will probably be similar, with the viewing axis of the telescope perpendicular to the long axis of the space station.

A.5.1.1 Configuration. Figure A-2 illustrates the Independent LTEP configuration. The Propulsion/Support Module (PSM) thrusters provide combined orbit correction and maintenance and coarse star-field pointing. Axial thrusters and attitude-control thrusters are provided. If a life-cell (a MOTEL or HOTEL) is provided for manned operation, it will be installed between the ATM Rack and the Propulsion/Support Module. It is not intended that the early life-cell will be occupied for extensive periods of time. During these periods, wherein the astronaut will occupy the MOTEL, repair, maintenance, inspection, and data package collection will be performed by EVA or by non-pressurized IVA through the hatch between the MOTEL and the ATM Rack. The astronaut(s) will be delivered by an Apollo CSM, which will dock with the Propulsion/Support Module and support the EVA directly or supply life-support gases into the MOTEL (pressurized compartment). It is assumed that precise star-field observation will not be accomplished during these initial manned periods.

An extension of the Independent operation is a manned mode tentatively planned for orbit operations in conjunction with the Space Shuttle or Space Station-remote vehicles. A crew of one or two astronauts would be stationed in the HOTEL life-cell for one-month (or longer) periods and would provide special telescope aiming and control and experiment programming without the restrictions of the large space station or space shuttle platforms. The HOTEL would also be mounted between the ATM Rack and the Propulsion/Support Module.

Because the AAP Cluster with its crew of three astronauts provides the worst-case "contamination" environment for the LTEP module, it has been selected as the reference for this study.

A.5.1.2 Orbit. The orbit of the initial-launch LTEP system, operating in conjunction with the AAP Cluster, will be 220 nm altitude with an inclination of 35 deg with the latitude plane through the Eastern Test Range (ETR). Later orbits, coincident with Space Shuttle and/or Space Station missions, may be as high as 350 nm altitude and inclined 50 deg to the ETR latitude plane. Because lower altitude orbits present a larger problem of particle concentration, this study used the 220 nm altitude as the baseline reference.

A.5.1.3 Telescope Pointing Limits. Figure A-3 illustrates the range of telescope pointing relative to sunlight illumination and the stellar field. Daylight stellar-viewing has been established as the critical mode for this preliminary study on the basis that the flux of contaminants in the field-of-view of the telescope and the illumination of the contaminants is considerably higher for the solar-lighted mode.

Because of the potential of the sun's rays entering the telescope tube, a sun shield has been provided at the aperture. Sensors automatically close the shield when the telescope LOS intersects any part of a 45 deg half-angle cone (except when the sun is occluded by the earth). The cone has its axis on the earth-sun centerline and its outer elements are tangent to a spherical locus with the radius equal to the earth's radius plus the orbit altitude.

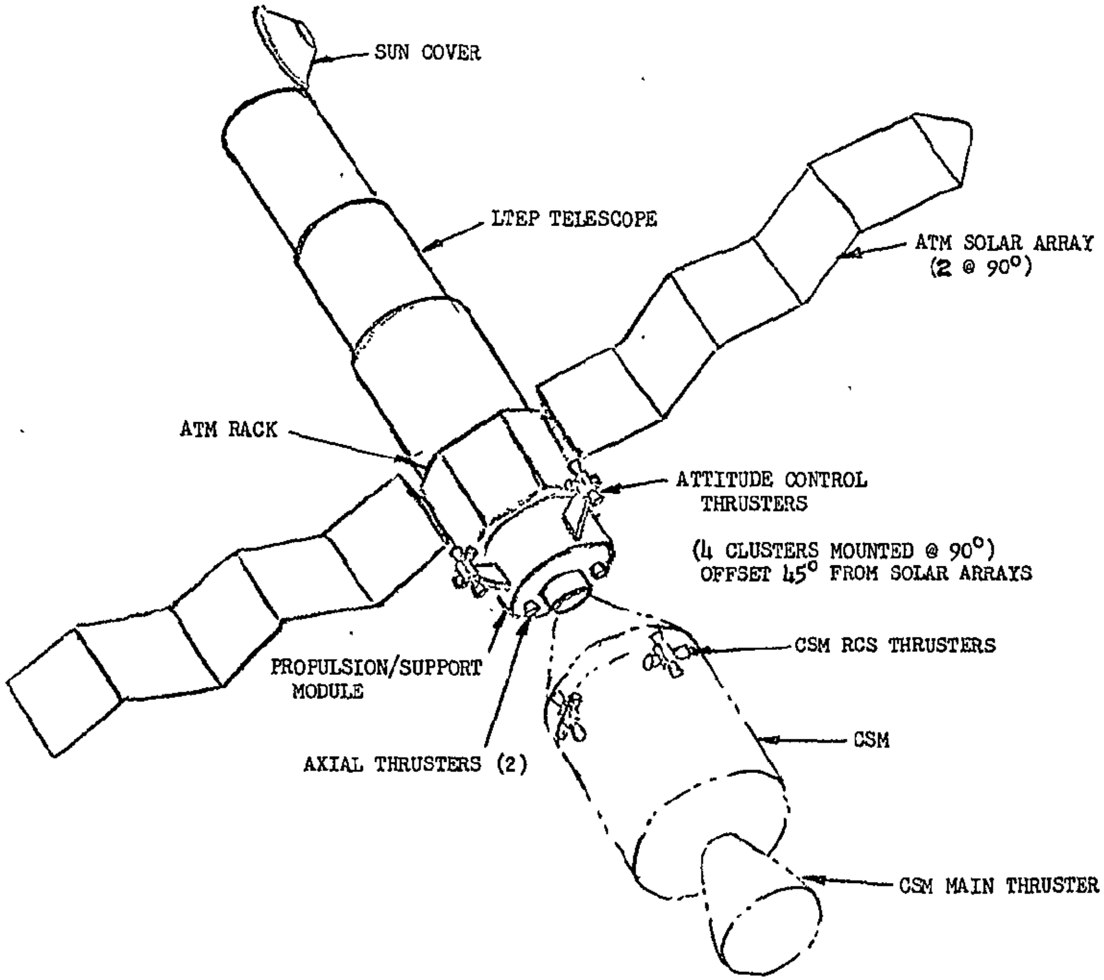

Fig. A-2 Independent LTEP Configuration

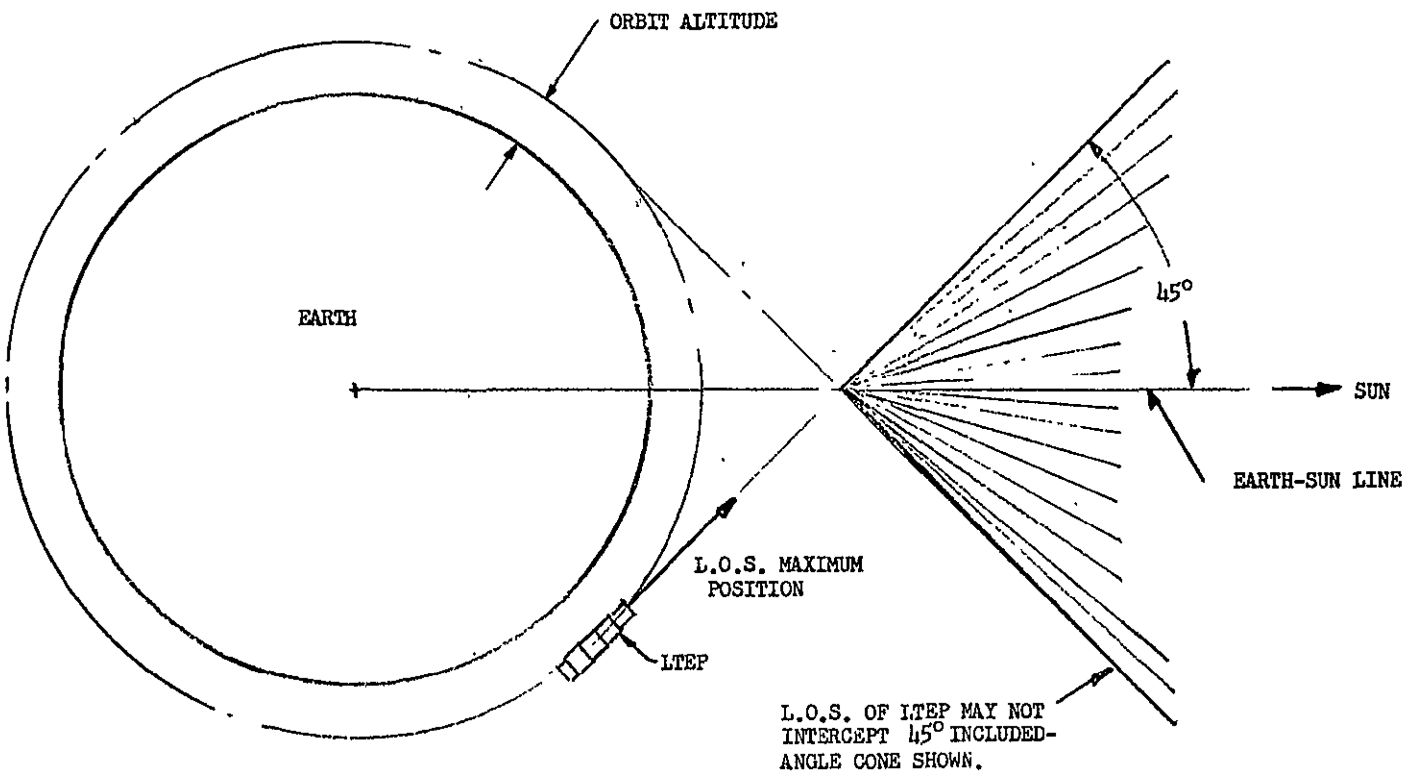

Fig. A-3 Viewing Limits of LTEP

A.5.1.4 Thermal Considerations. Because the internal optical surfaces are considerably colder than the external surface temperatures, and probably colder than local contaminants, the possibility of "cold-plate" collection of contaminants has been considered. Figure A-4 lists the approximate temperatures in the power-on operating mode.

A.5.2 LTEP Optical Features

Figure A-5 illustrates the diffraction-limited Cassegrain telescope optical configuration and lists the characteristics which have an interface with portions of this study.

A.5.3 Phenomena of Optical Viewing Degradation

The various means by which the light from a target star may be diminished or blanketed by background illumination, or by which optical surfaces may be degraded, is presented following. These phenomena were examined relevant to the effect of emissions from the LTEP system.

A.5.3.1 Stellar Light Intensity. For reference purposes in later discussions of the effect of contaminant and its degrading effect as background illumination, a cursory review was made of starlight intensity. Reference 7-25 indicates that the intensity per unit area for a 12th magnitude star in the focal plane of an astronomical telescope with 60 cm aperture and 200 cm focal length at a wavelength of 1000 Angstrom is:

$$5.4 \times 10^{-4.6}\ I_{sun}, \text{ where } I_{sun} = \text{Sun's intensity*}$$

This compares with a value of $7.0 \times 10^{-9}\ I_{sun}$ for the intensity of background illuminance caused by scattering of sunlight from the earth's atmosphere. Intensity per unit area in the focal plane of a telescopic star sensor with 5 cm aperture and 50 cm focal length at 3000 Angstrom for a 2nd magnitude star is:

$$1.4 \times 10^{-4}\ I_{sun}$$

This compares with an equivalent value of $10^{-11}\ I_{sun}$ for background illuminance resulting from sunlight scattering from the earth's atmosphere. The ratio of I_{sun}/I_{star} for light intensities at 1000 Angstrom is equal to $10^{15.6}$ (I_{star} is the light intensity of a star with visual magnitude of 12.) First magnitude stars are visible when the background daylight illumination is 10^{-8} ssb maximum (ssb = average Sun's surface brightness). Figure A-6 shows the relative brightness of background versus visible star magnitude (see Reference 7-26). An LMSC analysis (Reference 7-2) indicated that a 1st magnitude star has an illuminance of 8.2×10^{-8} foot candles. Solar illuminance was given as 1.35×10^{5} lumens per square meter.

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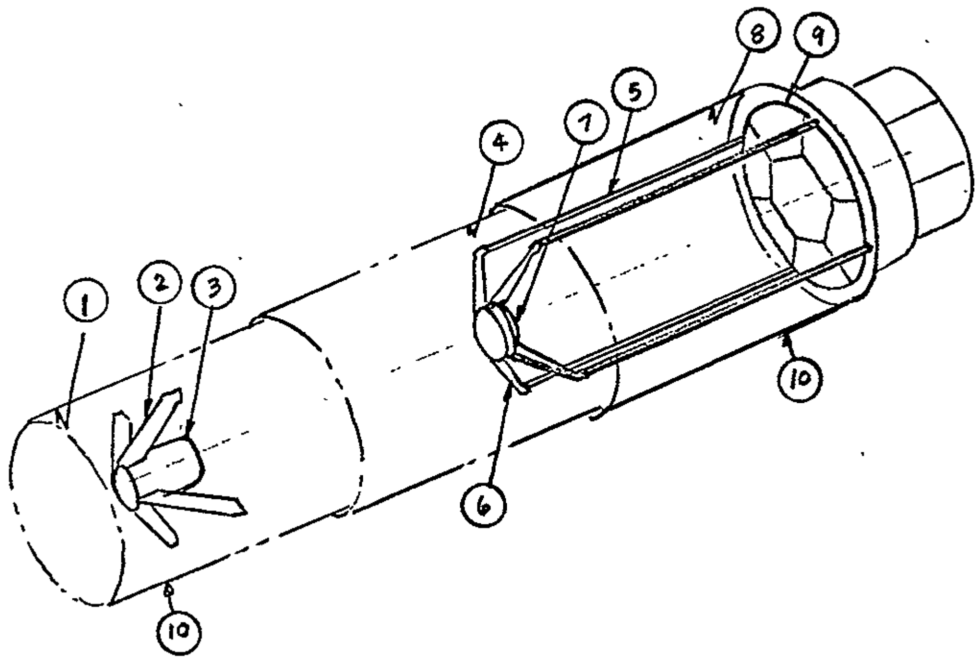
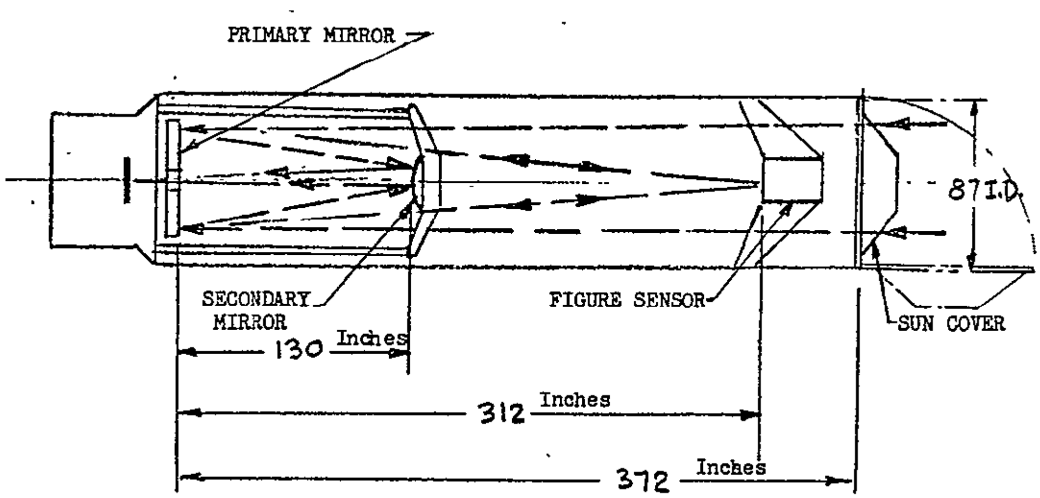
*The sun has a stellar magnitude of -26.8; $\frac{I_{star}}{I_{sun}} = 10^{-\left[\frac{26.8 + m}{2.5}\right]} = 10^{-15.6}$ for 12th mag. star.



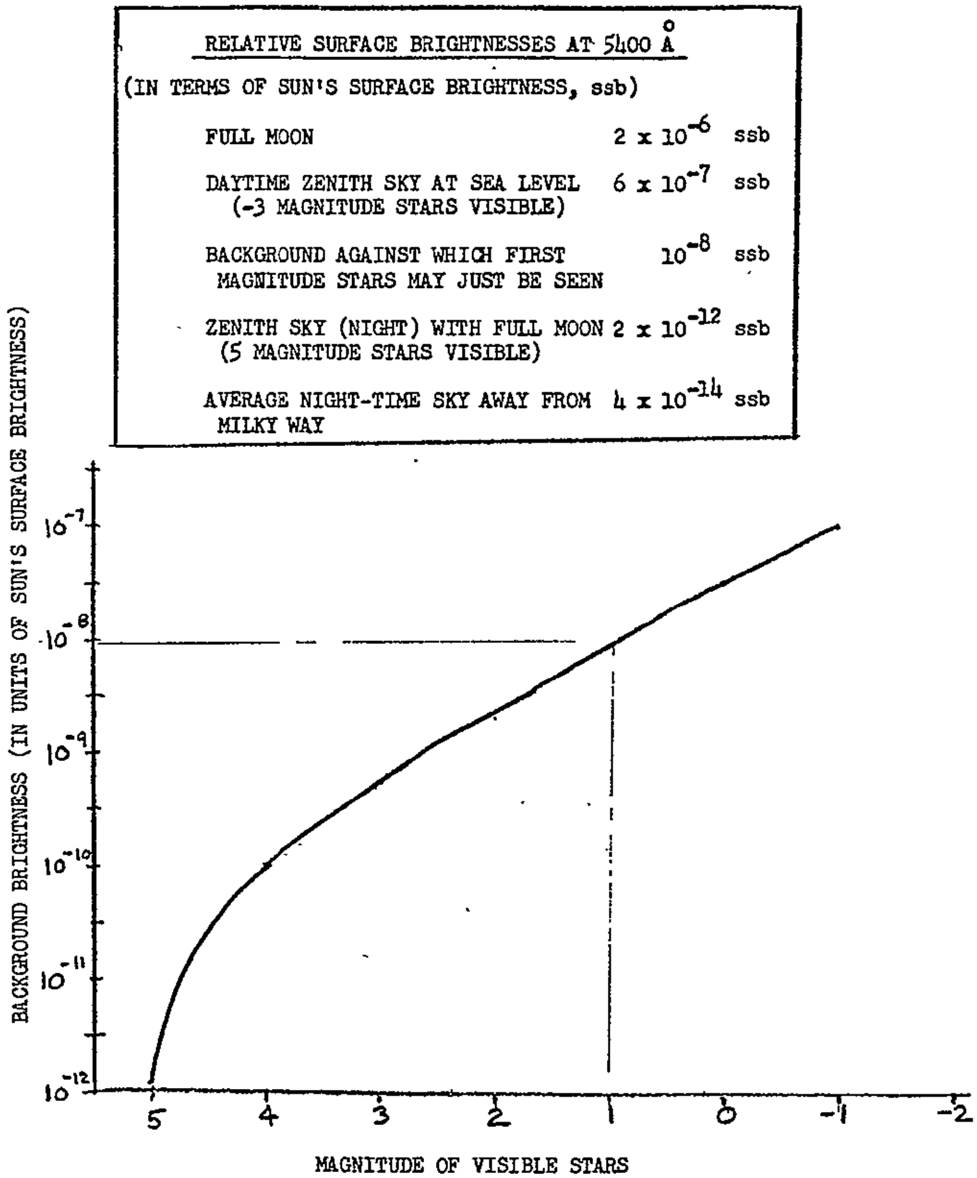
1	INNER SURFACE TELESCOPE TUBE-OPEN END NEAR FIGURE SENSOR	-202°F
2	FIGURE SENSOR SUPPORTS	-172°F
3	FIGURE SENSOR	-176°F
4	INNER SURFACE TELESCOPE TUBE-NEAR SECONDARY MIRROR	-125°F
5	QUARTZ RODS-SUPPORTING SECONDARY MIRROR	-101°F
6	SECONDARY MIRROR SUPPORTS	-122°F
7	SECONDARY MIRROR	-123°F
8	INNER SURFACE TELESCOPE TUBE-NEAR PRIMARY MIRROR	-100°F
9	PRIMARY MIRROR	- 81°F
10	EXTERNAL TELESCOPE TUBE	-109°F to -124°F

Fig. A-4 Approximate LTEP Telescope Operating Temperatures – Power ON



PRIMARY MIRROR	78.8 INCH DIA (2M)
SECONDARY MIRROR	16 INCH DIA
FIGURE SENSOR	AT CENTER OF RADIUS OF CURVATURE OF PRIMARY MIRROR
SUN-SHADE (COVER)	CLOSES WHEN SUN-LINE IS WITHIN 45° OF L.O.S.
FIELD OF VIEW	30 ARC MIN. (DIA.)
VIEWING CAPABILITY	12th AND LOWER MAGNITUDE STARS
WAVELENGTH	VISIBLE LIGHT

Fig. A-5 Optical Characteristics of LTEP Telescope



Note: Data from Reference 8.2

Fig. A-6 Star Magnitude Versus Limiting Background Illumination

A.5.3.2 Sunlight Scattering. Reference 7-25 states that one of the primary degradations of viewing occurs as a result of background illumination from sunlight scattering against contaminants in the telescope field-of-view. Table A-1 summarizes the relative sunlight scattering occurring as a result of "average" distribution of dust, etc., in the earth's atmosphere at various altitudes (as viewed toward space perpendicular to the earth's surface). The second column lists the total quantity of molecules stacked above a square centimeter area at the altitude indicated. The background illumination for a 217 nm altitude is $1.3 \times 10^{-10} I_{sun}$ resulting from a "density" of 4.6×10^{15} molecules per square centimeter.

Table A-1

SUNLIGHT SCATTERING FROM EARTH ATMOSPHERE AT VARIOUS ALTITUDES

Orbit Altitude	No. of Molecules Total*	Light Intensity**	
		Star Sensor***	Astronomical Telescope****
108 nm	2.5×10^{17}	10^{-11} I_{sun}	7.0×10^{-9} I_{sun}
162	1.56×10^{16}	6.4×10^{-13}	4.4×10^{-10}
217	4.6×10^{15}	1.8×10^{-13}	1.3×10^{-10}
270	1.9×10^{15}	7.5×10^{-14}	5.3×10^{-11}
325	6.5×10^{14}	2.6×10^{-14}	1.8×10^{-11}
370	4.5×10^{14}	1.8×10^{-14}	1.3×10^{-11}

Note: Data from Reference 7-25.

*This number represents the summation quantity of all molecules existing in a cylindrical "tunnel" above the altitude specified with a cross-section of one cm^2 (viewing up and perpendicular to the earth's surface).

**Light intensity is in terms of the sun's relative intensity, I_{sun}, and is the light intensity per unit area in the focal plane due to light scattering.

***Wavelength of light considered is 3000 Angstroms; aperture = 5 cm

****Wavelength of light considered is 1000 Angstroms; aperture = 60 cm

Although the star's image normally has a greater light intensity per unit area than the sunlight scattered from both the earth's atmosphere and contaminants, the area illuminated by the star's image is small compared with the whole of the detector's area illuminated by scattered sunlight. Therefore the total amount of light flux received by the detector from scattered sunlight compared with that received from a star is dependent on the FOV of the detector.

Sunlight scattered from the earth's atmosphere gives homogenous background illumination; contaminants may be non-homogenous and dependent on positioning of the star sensor or telescope relative to the contaminant sources and dispersion patterns.

Viewing of IR energy sources is more critical than with visible light. Gaseous particles in the vicinity of the LTEP vehicle would tend to scatter the input. Although LMSC has done some work in this area, as represented in Ref. 7-7, the scope of this study has been limited to inspection of visible light effects.

Reference 7-27 contains a formula for determining luminance "B" produced by scattering from dust particles:

$$B = \left[F \;\Sigma_i \;(\delta + A_i \,\Omega_i)\right] \; f\,(n, a)$$

F = solar constant

δ = 0 for screened sun, = 1 otherwise

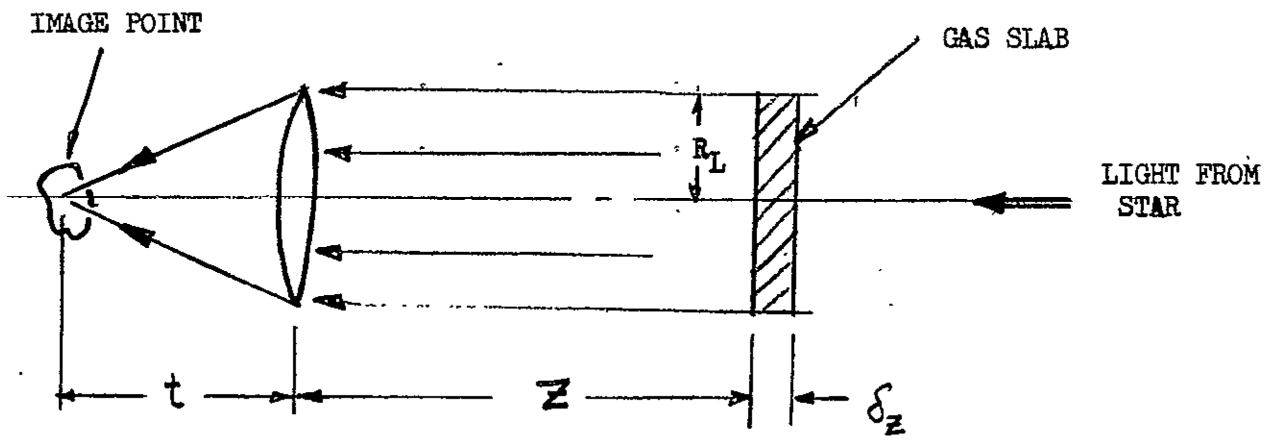
A_i = diffuse albedos of earth, moon, spacecraft, or other objects in vicinity

Ω_i = solid angles subtended

$f\,(n, a)$ = scattering function which is dependent on type of scattering, number density, and area of particles

Reference 7-25 offers another method for calculating scattered light. Figure A-7 illustrates this method. The amount of light received by an optical system from a volume of gas is dependent on the depth of that volume and the number of molecules per cm^3 therein. There is no dependence upon the linear distance of the volume from the optics along the LOS.

A.5.3.3 Optical Surface and Gas Molecule Reactions. Various reactions take place between gaseous particles and materials; they include outgassing, absorption, desorption, and sublimation. When a substance is in a gas environment, it is struck by fast-moving molecules. These may be trapped on the surface (adsorbed) or rebound. Some of the gas may enter the interior of the solid by diffusion or injection (absorbed). Molecules may gain sufficient energy to leave the surface (desorption). The surface may ultimately become saturated with gas molecules and an equilibrium condition occur wherein the absorption rate equals the desorption (at a given temperature and pressure).



δ_Z = GAS THICKNESS

LUMINOUS INTENSITY OF GAS SLAB = $K\,N\,I_{sun}\,\delta_Z$

N = number of molecules per cm^3

I_{sun} = incident illumination from sun

LIGHT INTENSITY AT IMAGE POINT = $K\,N\,\pi \dfrac{R_L^2}{t^2}\,\delta_Z\;I_{sun}$

SUMMING 0 to ∞ , TOTAL LIGHT INTENSITY PER UNIT AREA AT IMAGE POINT IS:

$$K\pi \frac{R_L^2}{t^2}\,\Big[NZ\Big]_0^{\infty}\,I_{sun}$$

THEREFORE, TOTAL INTENSITY PER UNIT AREA PRODUCED BY SCATTERED SUNLIGHT IN THE FOCAL PLANE =

$$K\pi\,\frac{R_L^2}{t^2}\sum_0^{\infty}\Big[N\,(Z)\,h\Big]\quad I_{sun}$$

h = THICKNESS OF VOLUME OF GAS

N = MOLECULES PER CM^3

Fig. A-7 Calculation of Background Light Intensity Created by Sunlight Scattered by Gas Molecules

A.5.3.4 Sublimation. Sublimation is a mechanism by which molecules of a substance may escape to the surrounding environment. This phenomenon is discussed in more detail in Section A.5.5.3.

A.5.3.5 Surface Sputtering. Damage to optical surfaces resulting from the impacts of space particles (at orbit velocity) over long periods of time is a potential degradation mode for the LTEP optical surfaces. Except for a cursory review of historical literature, no effort was expended in this area. Early calculations (Ref. 7-2) indicated that a surface removal rate on aluminum structure would be 40 microns per year at an orbiting altitude of 150 statute miles. At 1000 statute miles altitude (hydrogen species only impacting) the sputtering rate would be less by a factor of 10^5.

A.5.3.6 Condensation of Gases in FOV and Upon Optical Surfaces. Because the inner surfaces of the telescope tube are colder than the ambient environment and of gases or particles which have entered the tube, it is possible that some condensation will occur, either into free-drift droplets or onto the cold surfaces. If droplets form in the FOV, there would be an increase in the intensity of scattered light, since scattering centers would be larger. The increase would be proportional to the number of molecules in each droplet, until the radius of the droplet became comparable with the wavelength of light.

Reference 7-25 includes a calculation of droplet sizes and equilibrium:

p = saturated vapor pressure

p_i = supersaturated vapor pressure

S_T = surface tension

P = pressure inside of droplet due to surface tension

b = radius of droplet

$$P = \frac{2\,S_T}{b}$$

P must be greater than $(p_i - p)$ for a droplet to form; therefore, a minimum droplet radius for condensation to form, is:

$$b = \frac{2\,S_T}{p_i - p}$$

If p_i is greater than p, then a droplet will grow in size and the degree of supersaturation will decrease until equilibrium is reached. With expansion of vapor $(p_i - p)$ decreases and the droplet starts to evaporate.

For a test condition using propane jets with an initial pressure of 5 psi, the gas reached supersaturated at 140°K. The maximum degree of supersaturation was found to be at 3.3×10^{-4} atmospheres and at 135°K. The equivalent surface tension, S_T, was 28.8 dynes per cm. Therefore,

$$b_{min.} = \frac{2 \times 28.8}{33 \times 10^2} = 1.7 \text{ mm}$$

These particles are very large and if present in sufficient quantity in the FOV would scatter sunlight, irrespective of propane condensation. When propane has cooled to 140°K, it is possible to condense it out on a colder surface.

The Gemini spacecraft jets (and the attitude control thrusters for LTEP) have a much higher nozzle pressure than the propane thrusters. The main product from the LTEP thrusters will be water vapor which has a lower saturated vapor pressure than propane and thus will produce condensation of much smaller particles, thereby increasing the potential light scattering.

A.5.3.7 Absorption of Light. Light absorption by gas molecules in the LTEP telescope FOV is a potential problem, but particularly in the ultraviolet region with wavelengths below 2000Å. Although analysis of the LTEP conditions has not been accomplished, the following is offered as background for follow-on studies.

By Beers law, 2 percent of light will be absorbed when light passes through a column of gas, 1 cm^2 in cross-section area, containing $2 \times 10^{22}/\sigma$ molecules. The quantity of molecules which can be tolerated in the FOV of the telescope before absorption exceeds the 2 percent threshold value is $2 \times 10^{14} \times A_L$, where A_L is the area in cm^2 of the limiting aperture.* In the IR range, Beer's law applies only at constant pressure; the amount of light absorbed by a constant mass of gas decreases as the pressure is reduced (less molecules per unit volume). This effect will not be so marked in the UV range, where the main cause of absorption is ionization of the gases.

Table A-2, data from Ref. 7-25 lists light absorption percentages for varying molecule packing in the FOV of a telescope with 6 cm diameter aperture at wavelength of 900 Å.

Absorption results in a photolysis or ionization of the gases. In the case of a propane jet (C_3H_8), products of hydrogen, propylene (C_3H_6), methane (CH_4), and ethylene (C_2H_4) were created by photolysis. For wavelengths below 1130 A, most of the light absorbed leads to gas ionization. These products from photolysis and ionization have a negligible additional effect on light absorption and scattering.

*Note: All gas molecules have approximately the same "diameter" at a given pressure, ranging from 2.30×10^{-8} cm for He to 4.68×10^{-8} cm for C_2H_4 (ethylene).

Table A-2

ABSORPTION VALUES FOR TELESCOPE HAVING 60 CM LIMITING APERTURE DIAMETER AT WAVELENGTH OF 900 ANGSTROMS

Quantity of Molecules in Front of Telescope	Percentage of Light Absorbed
5.65×10^{17}	2
8.0×10^{17}	2.8
10^{18}	3.5
2.0×10^{18}	6.85
4.0×10^{18}	13.15
7.0×10^{18}	21.9
10^{19}	29.8

A.5.3.8 Refraction of Light Rays and Scintillation. The path of a light ray travelling through a gas mass of varying densities (stratified) is altered due to the variations of refractive index. This could cause scintillation of the star's image (in a star sensor) and noise in the optical control system. Because the thickness of refracting gas layers are normally small in comparison with the aperture size, scintillation will probably not occur in the LTEP system. However, a quantitative analysis should be made in follow-on studies.

A.5.3.9 Chemical Reactions on Optical Surfaces. If it is assumed that all of the oxygen swept up by the open telescope tube in the orbit path of the LTEP chemically reacts with surface material in accordance with predicted probability, the net result is an equilibrium condition in which sputtering effects are less serious (because those atoms which are combining chemically are not expected to be sputtered in the same collision). The oxide layer may act in one of two ways to protect the surface; it may form a surface coating which is less easily sputtered, or it may form a surface which is preferentially removed. Other factors such as absorption, chemisorption, or diffusion will tend to reduce the severity of the attack.

Although the occurrence of oxygen in LTEP system emissions has been determined in this preliminary study, no analysis of the detail surface effects was accomplished. This should be accomplished in follow-on analysis and/or test effort.

A.5.4 Exhaust Products from Thrusters

LMSC has found experimentally that surfaces as far away as 38 nozzle diameters from the thruster centerline are susceptible to contamination by expansion in a vacuum of plumes of sub-micron and micron-size particles. Even surfaces behind protective barriers or facing away from the rocket plume can be contaminated. Both solid-propellant and liquid-rocket motors emit solids or liquids as well as gases and water vapor by normal or complete combustion. The characteristics of the flow field, potential distribution about the LTEP telescope, constituents of the plume, and potential effects are described following.

A.5.4.1 Location of Thrusters on LTEP System. The LTEP will be flown as part of an AAP Cluster or in an Independent mode. These two basic configurations are shown in Fig. A-8. The Dry Workshop Cluster will use bi-propellant Reaction Control System (RCS) thrusters similar (or identical) to those presently used on the Apollo CSM and LM. These thrusters will be used for orbit positioning and Cluster maneuvering. It is currently uncertain as to the need of these thrusters to perform momentum dumping from the Control Moment Gyros (CMGs) and to perform coarse pointing corrections for the ATM, therefore, it has been conservatively assumed that an additional set of thruster clusters will be installed on the SIVB Workshop. A position has been assumed as shown in Fig. A-8. It has been assumed further that the RCS thrusters will be operating during an LTEP system operational period but that the CSM will be dormant and its thrusters inactive.

The exhaust plumes of the Workshop thrusters have their closest source points about 600 inches from the aperture opening of the LTEP telescope, and with plume centerlines about 260 inches from the telescope LOS and tilted 45 deg to the LOS. The axial thrusters on the Propulsion/Support Module of the Independent LTEP exhaust 180 deg from the telescope pointing direction. During use of these thrusters for orbit-position changes or major maneuvers, the telescope will probably be caged and the sun shield closed.

The attitude control thrusters of the Independent LTEP system will be used for coarse-pointing during target star-field acquisition and for primary orientation corrections (such as CMG momentum dumping). The telescope may be caged during the maneuvering. The nozzle-exit sources of the plumes are 480 inches from the aperture of the telescope and the plume centerlines are 100 inches outboard of and parallel to the telescope LOS.

A.5.4.2 Thruster Plume Characteristics. Figure A-9 illustrates schematically the plume flow-field of a typical thruster. LMSC has a computer program which is based on a modified Newtonian flow theory. It has been determined by preliminary analysis using a simple flow model that the problem of surface contamination by a plume is amenable to analytical solution. For some quantitative data this analysis must be broadened to incorporate incomplete combustion and two-phase flow effects.

A.5.4.3 Propane Plume Density Variation. Plumes will decrease in local density of molecules as the distance from the nozzle exit plane increases. Table A-3 contains a tabulation of molecule density of a propane jet at distances up to 250 cm from the nozzle exit plane. This example is used to illustrate the dispersion characteristics of a gas released with an initial velocity.

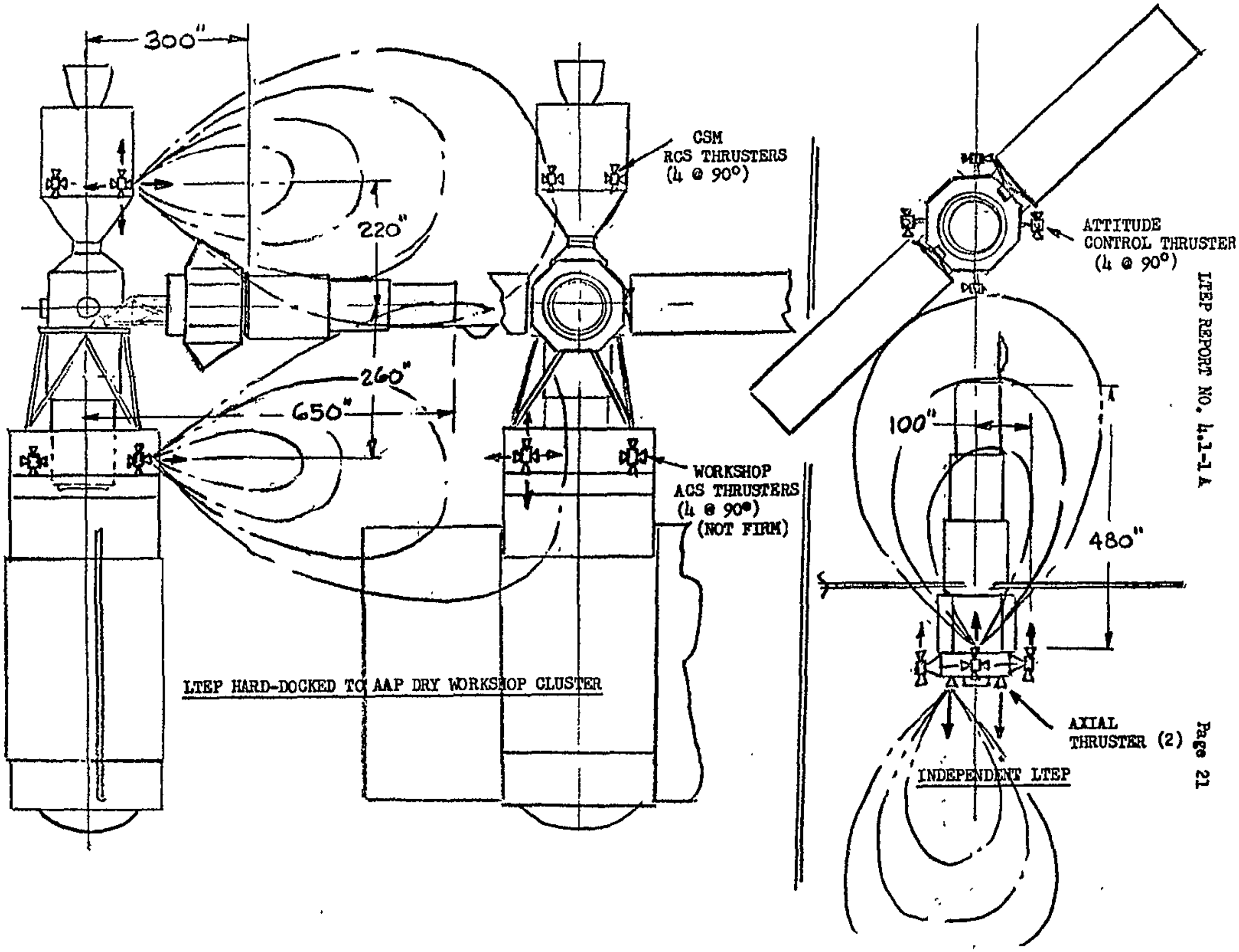
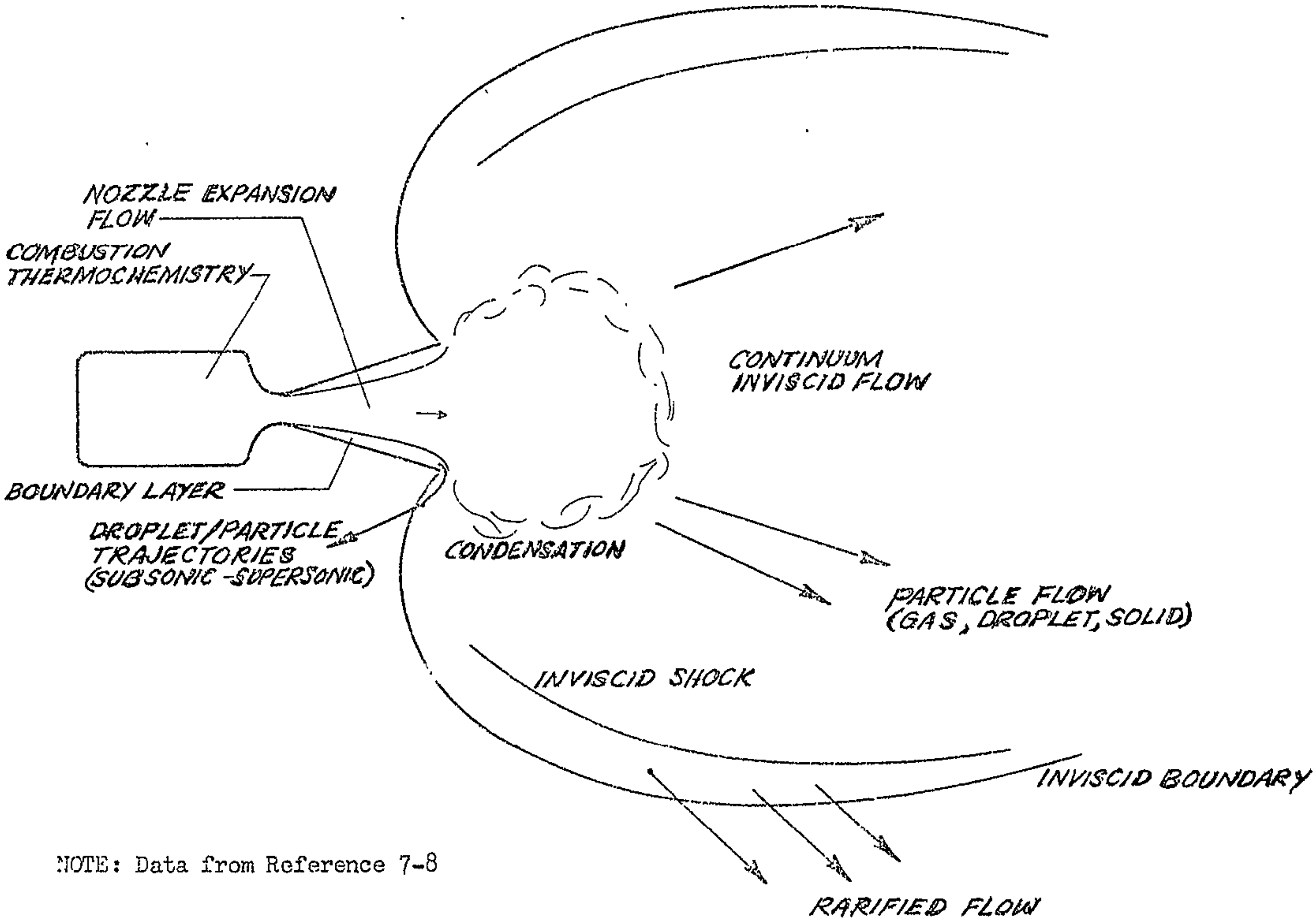


Fig. A-8 Location of Thrusters on LTEP Systems

(TYPICAL THRUSTER)



NOTE: Data from Reference 7-8

Fig. A-9 Flow Field Schematic

Table A-3

PROPANE JET DENSITY CHANGE WITH DISTANCE FROM NOZZLE

Distance from Nozzle (cm)	Density (molecules/cm^3)	Total Molecules in Column of 1 cm^2
0 → 0.6	2.6×10^{17} to 10^{17}	1.33×10^{17}
0.6 → 1.33	10^{17} to 10^{16}	2.4×10^{16}
1.33 → 3.33	10^{16} to 10^{15}	6.6×10^{15}
3.33 → 9.4	10^{15} to 10^{14}	2×10^{15}
9.4 → 26.7	10^{14} to 10^{13}	5.7×10^{14}
26.7 → 77.5	10^{13} to 10^{12}	1.62×10^{14}
77.5 → 250	10^{12} to 10^{11}	5.7×10^{13}

Note: Data from Reference 7-25.

A.5.4.4 Cold-Gas and Hot-Gas Plume Density Variation. Some low-impulse attitude control systems utilize cold gas ejected from nozzles for thrusting; these are particularly useful when very small impulses or vernier control is required. Reference 7-9 provided an example: Nitrogen gas (which before expansion was at a temperature of 520°R) was reduced 20° to 50°R and at 10 feet from the nozzle had a density of 32.2×10^{-8} lb/ft^3 and a local pressure of 2×10^{-5} psia. At 24 feet from the nozzle, the density was reduced to 64.4×10^{-9} lb/ft^3 and the pressure had lowered to 5×10^{-5} psia.

For a hot-gas thruster of 100 lb thrust level (similar to the LTEP or Cluster thrusters) at 15 feet from the nozzle the gas density was calculated to be 26×10^{-8} lb/ft^3.

A.5.4.5 Type of Contaminant from Thrusters. The bi-propellant thrusters on the CSM, the Workshop, or the LTEP Propulsion/Support Module utilize nitrogen tetroxide (N_2O_4) and Aerozine 50 (compound of monomethyl hydrazine). The chemical reaction is:

$$N_2O_4 + 1/2\, N_2H_4 + 1/2\, (CH_3)_2\, N_2\, H_2 \rightarrow 2\, N_2 + 1/2\, CO + 1/2\, CO_2 + 2\text{-}1/2\, H_2O + 1/2\, H_2$$

The percentages by weight of these exhaust products are:

CO	10%
CO_2	16%
H_2	1%
H_2O	33%
N_2	40%
Total	100%

If a monopropellant such as hydrazine is used for attitude control thrusting, the chemical reaction (through a platinum catalyst) is:

$$3\,N_2H_4 \longrightarrow 1.6\,NH_3 + 2.2\,N_2 + 3.6\,H_2$$

The percentages by weight of the exhaust products are:

NH_3	28%
N_2	64%
N_2	8%
Total	100%

A.5.4.6 Thruster Contaminant Flux. The estimated quantities of attitude-control bipropellants and the usage rate maximums of the thrusters are given in Table A-4.

Table A-4

THRUSTER EXHAUST PRODUCT RATES

Usage	AAP Cluster		Independent LTEP	
	Total (lb)	Max Rate (lb/hr)	Total (lb)	Max Rate (lb/hr)
1. Maximum CMG Spin-up for 6 Orbits	7	1.0	2	0.3
2. Single-Orbit Hold Without CMG	2	1.4	0.2	0.1
3. CSM Docking (stabilizing)	3	0.6	1	0.2
4. Partial Backup – CMG Desaturation	40	80	6	12
5. Star Coarse Pointing (each occurrence)	4	8	0.4	0.8

In general, only the last two modes shown in Table A-4 will be used during a continuous stellar-pointing period. Also, during the time that the thrusters are on or activated, the LTEP fine-pointing and optical control systems are incapable of steady-state stellar extra-fine pointing. It must be assumed therefore that contaminant fluxes resulting from "one-shot" operation of the thrusters preceding a stellar pointing period will not directly affect the ambient environment around the LTEP; at least, the contaminants will be in a decaying mode during the stellar lock-on following opening of the sun shield (the sun shield should remain closed during all attitude control thrusting).

Also, only a portion of the thrusting would be through nozzles directed generally toward the FOX tunnel of the telescopes (4 nozzles in each thruster package, each nozzle thrust line oriented 90 deg from the adjacent). The estimated contaminant flux directed from the Dry Workshop thrusters is approximately 4 lb for each coarse pointing maneuver. Assuming that the maneuver will take about 0.5 hr, the usage rate is estimated at 8 lb/hr. With the Independent LTEP, the maneuver is estimated to take 0.4 lb of propellant used at a rate of 0.8 lb/hr.

A.5.5 Outgassing and Contaminant Leakage and Venting

The AAP Cluster provides the maximum contaminant-emission environment for the LTEP system. The Independent LTEP system, operating unmanned or with more limited crew, will have a much lower leakage/venting rate. When the CSM is docked, the outflow of contaminants will increase, but during these periods the telescope will probably be in a non-operating mode (for repair or maintenance). The following is a discussion of the sources, types, and quantities of contaminants which may affect the LTEP system functions.

A.5.5.1 Life-Cell Leakage and Venting. The primary expendables stored in the AAP Cluster (from Ref. 7-22) and the estimated "continuous" outgassing or venting rates over a 56-day man-occupied period are listed in Table A-5.

Urine venting will occur as water vapor (boiled off to external vacuum from the life-support subsystem) and will average about 3 lb per day. This amount has been included in the 14 lb per day total of all H_2O vent and leakage. There potentially will be also a small amount of solids vented overboard with the water vapor; it is estimated that a maximum of 1 percent by weight or 0.03 lb per day will be vented as solid particles. This is residual of the initial 5 percent solids in the urine before the vaporizing process. The solids will be salts and organic matter.

The actual solid particle emission should be quantitatively determined in follow-on studies. The amounts are believed not to contribute significantly to light absorption or scattering, but they may contribute to the long-term optical surface contamination or to surface chemical reaction.

The probable sources for minor leakage are fairly generally distributed throughout the Dry Workshop Module (DWS), the Airlock Module (AM), the MDA, and the CSM. Primary leakage will probably occur at the AM attachment to the DWS and MDA attachment to the CSM. Venting occurs primarily from the AM area. In all cases the source points will be at least 500 inches from the telescope tube aperture (see Fig. A8).

Table A-5

OUTGASSING/DUMPING FROM AAP-4 CLUSTER

(For 56-Day Manned Operation)

Item	Total Available (lb)	Average Rate of Outgassing or Dumping (lb/day)
H_2O – Vent and Leakage	790	14
O_2 – Metabolic	336	6
O_2 – Leakage	608	11
O_2 – Molecular Sieve	107	1.6
O_2 – Airlock Vent* (18 Repress)	(45)	–
O_2 – Total (Without Air Lock Vent)*	1051	18.6
N_2 – Leakage	186	3.3
N_2 – Molecular Sieve	33	0.6
N_2 – Airlock Vent* (18 Repress)	(14)	–
N_2 – Total (Without Airlock Vent)*	219	4
Urine Vent – Vaporized H_2O	–	(3)**
Urine Vent – Solid Particles	0.15 lb/day	0.03
Suit Loop Vent*	–	Not Determined – Periodic with EVA

*Note: No EVA when telescope is stellar-pointing. One airlock vent is planned for each 3-day period (average). Venting assumed to take 0.5 hr.

**Note: 3 lb/day of urine H_2O vented is included in the 14 lb/day total for "Vent and Leakage" of H_2O.

Assuming random location of leakage points, only a small amount of the total leakage will initially be directed toward the stellar-pointing target and the net percentage of contaminants passing through the telescope FOV will probably be small.

A.5.5.2 Subsystem Contaminants. The various subsystems supporting the LTEP will potentially supply contaminants in three specific areas: (1) battery venting, (2) pyrotechnic device products, and (3) materials outgassing or sublimation. The latter is discussed separately in paragraph A-5.5.3.

a. Battery Venting. The Apollo Cluster (less the CSM) utilizes electrical power subsystems comprising solar arrays and batteries. The batteries on the ATM Rack are nickel-cadmium type, hermetically sealed in high-pressure containers (1000 psi) and do not require venting. The batteries in the Airlock Module are also nickel-cadmium, operating at a normal internal pressure of 5 to 15 psi. In cases of malfunction, these batteries vent overboard through a relief valve set at 250 psi.

   In the CSM, the electrical power system comprises fuel cells and batteries. The batteries are non-sealed silver-zinc type which are continuously vented overboard through a relief valve set at approximately 25 psi. The two batteries contain about 1000 cc of fluid each; it is estimated that 10 percent would exhaust overboard during a 56-day Cluster operating period if the CSM were active. The exhaust products are gaseous hydrogen and water vapor. Because the CSM is partially dormant in the Cluster-attached mode, the rate of battery venting is estimated to be less than 2 cc per day, a negligible amount amount relative to LTEP system contamination.

b. Contaminants from Pyrotechnic Devices. Most pyrotechnic devices are powered by a solid propellant. Ignited by an electrical-resistance-heated fuse, the typical reaction of the boron/potassium-nitrate compound is:

$$2B + 2\,KNO_3 \longrightarrow B_2O_3 + K_2O + N_2 + O_2$$

   The percentage by weight of the exhaust products would be:

B_2O_3	32% (solid)
K_2O_3	42% (solid)
N_2	12%
O_2	14%
Total	100%

   The total weight of potential contaminants would be less than one pound.

During the launch-ascent phases and initial orbit operation the telescope tube interior would be sealed-closed by the sun shield. During this period, most of the pyrotechnic devices would be actuated; the following functions are typical:

- Payload shroud jettison
- Separation of Cluster/LTEP or LTEP Module from launch vehicle
- ATM rack swing-link release
- ATM rack extend-lock
- Propellant isolation valve opening
- Solar array release (for unfold)
- Antenna boom release
- Telescope tube release (for extend)
- Telescope tube lock (extended)

The probability of residual pyrotechnic subsystem contaminants in the space surrounding the LTEP orbiting system is considered to be small. However, deposition of solid exhaust products and debris on the external surfaces of the telescope, solar arrays, and external lenses is possible and should be examined in detail in follow-on studies.

A.5.5.3 Materials Outgassing on Sublimation. One of the potentially significant sources of contaminants to the LTEP system is outgassing from or sublimation of its own materials, particularly those located within the cavities containing the optical surfaces. Volatile elements or sublimed particles may deposit or condense on lenses or mirrors and cause a gradual change in optical properties. The following data describes the basic phenomena and the candidate types of contaminants and sources.

a. Sublimation or Evaporation of Material from Plastic Parts. Non-metallic parts and coatings are more complex than metals because they contain a variety of ingredients. Although the basic polymer is not likely to have a high enough vapor pressure to cause significant loss of material in vacuum, some other ingredient may. Specifically, plasticizers used in many plastics have relatively high vapor pressures and can readily outgas. A typical example:

Plasticizer Loss to Space

	At 22^{o}C	At 100^{o}C
Vapor Pressure	10^{-4} to 10^{-2} mm Hg	0.1 to 1.0 mm Hg
Loss Rate	1 to 100 g/cm^2-day	1000 to 10000 g/cm^2-day

It may be observed that the loss rate is relatively high and total outgassing can occur in a comparatively short time in vacuum environment. Other plastics outgas because of evaporation of impurities rather than sublimation of basic materials. As an example, phenolic materials emit considerable gas (water, air, and CO_2). Also, cellulose acetate typically emits vapor and air (no organic fragments).

Tests have indicated significant weight losses in non-metals at elevated temperatures (300°F and higher in a vacuum). Lower weight losses occur at lower temperatures and at some equilibrium point (temperature varies) there is essentially zero loss. In a test discussed in Ref. 7-28, "insignificant" losses occurred at room temperature (70°F) on vacuum-cured specimens. In most cases, the major percentage of the weight loss occurred during the first 30 hours of the 100-hour exposure time at the elevated temperature. The fact that some weight loss was observed at room temperature on samples which had not been vacuum-cured or vacuum-baked prior to test indicates the desirability of vacuum-baking of all plastic flight articles prior to usage in space vacuum to reduce the outgassing potential to a minimum.

In most cases, the vacuum stability of an inorganic material will be acceptable; however, its bond to the substrate may offer a problem. Organic materials generally tend to emit volatiles or to depolymerize and sublime in a vacuum and their use should be screened carefully and tests performed to verify their characteristics under anticipated temperature conditions. Because materials have not yet been selected for the LTEP system, the specific outgassing products and approximate rates must be determined in follow-on study effort.

b. Sublimation or Evaporation of Metals. In general, metals will not be affected by the vacuum environment. Evaporation at lower temperatures will be insignificant except for cadmium and zinc; these metals should be avoided both as elements and alloyed with other metals. These metals have shown a definite but small weight loss over long periods of time in vacuum. Being fairly heavy elements, they would readily tend to deposit on optical surfaces in the vicinity and perhaps amalgamate with other metals. Also, at temperatures above 250°F, use of magnesium or other light metals should be avoided because of the sublimation/evaporation hazard (for structure near optical surfaces).

The maximum rate of loss of a pure material in high vacuum has been calculated from kinetic theory to be (Ref. 7-28):

$$G = \sqrt{\frac{M}{T}} \times \frac{p}{17.4}$$

where

G = rate of loss in g/sec-cm^2 of exposed surface

M = molecular weight of material

T = temperature in $^{\circ}$K

p = vapor pressure in mm Hg at temperature T

Application of typical element metals shows that few will lose appreciable material at temperatures much below their melting point although there are important exceptions, such as the forementioned magnesium:

Material	Loss of Metal to Space	
	Melting Point (^oC)	Temp for Loss of 1 g/cm^2-year (^oC)
Cs	29	25
Na	98	130
Mg	651	250
Al	660	690

The determination of the amount of loss of one element from a metal alloy is more more difficult and usually tests are necessary to determine the specific characteristic.

c. Volatilization of Lubricants. Considerable vacuum testing on lubricants (oils, grease, etc.) has been accomplished by LMSC and other companies and Government agencies. In general, oils and greases will tend to volatilize or depolymerize more or less readily and should be avoided in LTEP system parts exposed to vacuum, particularly in the optical system cavities. Special hard coatings or inorganic or metal compounds such as moly-disulfide should be considered for use.

d. Other Volatiles. The inadvertent inclusion of other volatile substances, which in the earth-atmosphere (sea level) will create no problem, will potentially cause a problem with outgassing in a space vacuum. The most common volatile is water. It can be trapped in anodic metal coatings, in absorptive materials, and in structural parts such as plastic laminates. Here again, the quantity of contaminant is not directly calculatable but precautionary methods in part fabrication, materials processing, and vehicle assembly and testing are mandatory if these residuals are to be diminished.

A.5.5.4 Astronaut Suit Emissions in EVA. When the astronauts are performing inspection, adjustment, or maintenance/replacement functions in EVA (extra-vehicular activity) mode, they will be using PLSS (portable life support system) backpacks to provide space-suit internal environment. These packs supply breathing oxygen, control temperature by sublimating water externally, and convert CO_2 to remove contaminants by internal processing through the LiOH canister.

The H_2O sublimed is about 1.5 lb/hr or 0.19 g/sec. This quantity is considerably higher than the average H_2O leakage and vent from the Cluster man-cells, which is 0.075 g/sec. With a 2-man EVA the flux of H_2O molecules could become quite large, approaching 1.2×10^{22} molecules emitted per second (compared with 2.55×10^{21} molecules of H_2O from the Cluster).

The suit also emits approximately 0.04 lb/hr or 0.005 g/sec of gases, primarily O_2.

The current space-suit outer covering contains considerable fiberglas particles which tend to fall out with astronaut movement. (It was reported from recent Apollo flights that these particles caused much of the total "debris" contamination within the CM and and LM compartments.) A modified coating or covering (such as dip-coated fabric, coated with non-subliming elastomer) will be necessary if the astronauts are performing functions near a telescope opening; such as near the aperture with the sun shield open or near an open mirror access panel in the base of the telescope cavity.

A.5.6 Movement of Contaminants Around or Within the LTEP Telescope

The phenomenon of gas or particle movement in the vicinity of the telescope tube and in the FOV has been surveyed. The characteristics which are pertinent to later determination of the LTEP-affecting flux are presented in summary form following.

A.5.6.1 Corona Around the Spacecraft. Some of the total contaminants tend to form a "cloud" around the spacecraft. Particle ejection from the spacecraft, such as leakage, is assumed to occur at a velocity "v" where, from Ref. 7-26,

$$P = 1/2 \ \rho \ v^2$$

when

P = internal pressure = $1/2 \times 10^6$ dynes/cm^2

ρ = assumed to be unity

Therefore, v = 10 meters/sec

Once in the "air-stream," the particles are accelerated by molecular impact. The acceleration produced is inversely proportional to the particle radius and equals 1000 cm/sec^2 for a one-micron particle in a vacuum of 10^{-12} grams/cm^3. A one-micron particle stays in the vicinity of the spacecraft for about one second and 100-micron particle for about 100 seconds. Because residence time is proportional to radius of particle and because scattered brightness per gram is inversely proportional to radius; a constant rate of ejection by the spacecraft will lead to a fixed value of brightness independent of the sizes of particles ejected, providing the particles have a radius greater than one micron. The calculation does not apply to particles smaller than about one micron because smaller particles would cause Rayleigh scattering of light and therefore be much less effective in producing an illumination cloud. Figure A-10 illustrates the correlation of mass ejection rate with the brightness of the spacecraft corona. A particle ejection rate of 2 lb/min will produce a background illumination of 10^{-8} ssb (ssb = equivalent solar surface brightness), the limit for viewing first magnitude stars (see Fig. A-6). A spacecraft corona of brightness 10^{-9} ssb requires about 2 lb/hr of mass ejection and 0.1 to 10 grams of particles in residence around the spacecraft. A rate of about 1 lb/hr or less would be necessary to allow viewing of 4th magnitude stars. The mass ejected usually ends up in the wake of the orbiting spacecraft.

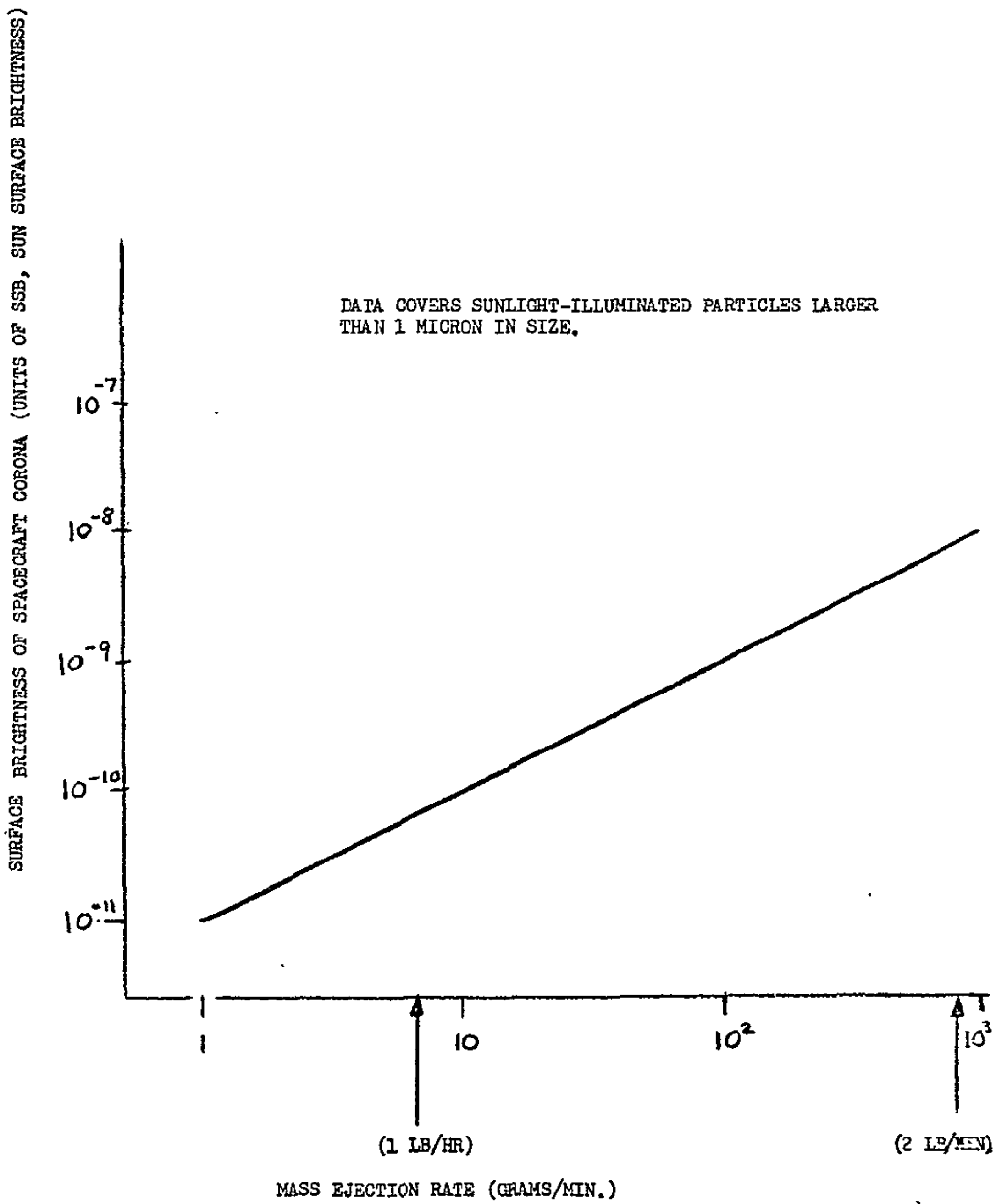


Fig. A-10 Calculated Brightness of Spacecraft Corona as Function of Mass Ejection Rate of Particulate Matter

The foregoing applies to agglomerates where molecules will combine into large particles. The diameter of various gaseous molecules range from 2.32×10^{-8} cm (for H_2) to 4.09×10^{-8} cm (H_2O); these respectively would be 2.32×10^{-4} micron and 4.09×10^{-4} micron, far smaller than the particle size required for production of the corona described.

A.5.6.2 Gas Held to Vehicle by Gravitational Attraction. According to Ref. 7-25, a molecule must have a velocity less than 2.7×10^2 cm/sec relative to the spacecraft to remain with the spacecraft as atmosphere. Although this is possible, collisions with the spacecraft and with other molecules already in space will keep the "held" quantities to a minimum or negligible level. The following formula was used to derive the velocity figure.

a. Escape velocity from gravitational field, U, is:

$$U = \sqrt{G\frac{M_s}{R_s}}$$

where G = gravitational constant = 6.7×10^{-8} dynes/cm^2-g^2

M_s = mass of vehicle (Kg)

R_s = radius of vehicle (cm)

b. From kinetic gas theory,

$$1/2\ M\bar{u}^2 = 2/3\ RT$$

where M = molecular weight (g)

$\bar{u}^2$ = average of square of velocities of molecules at temp, T

T = temperature

R = gas constant

c. Equating the two velocities U and $\bar{u}^2$,

$$\bar{u}^2 = 4/3\frac{RT}{M} = 4/3 \times \frac{8.3}{60} \times 10^7 \times 10^{-10}$$

$$u^2 \cong 7.4 \times 10^{-4}$$

$$u = \sqrt{u^2} \cong 2.7 \times 10^{-2}\ \text{cm/sec}$$

A.5.7 Effects of Outgassing and Contaminants on LTEP

The various types and quantities of contaminants have been discussed in previous paragraphs. A summation of these data, extrapolation for the LTEP, and a preliminary analysis of effects follows:

A.5.7.1 Contaminant Flux Distribution About the Spacecraft. It was assumed for initial analysis that outgassing and venting contaminants would be emitted in random manner from the AAP Cluster or from the Propulsion/Support Module or man-cell modules of the Independent LTEP spacecraft. Dispersion was assumed to occur in a spherical mode where density of the contaminant "cloud" would decrease rapidly in radial directions away from the source points. Based on historical assumptions, the contaminant cloud will disperse from the general vicinity of the spacecraft within approximately one second (gaseous particles and those less than about one micron size). An input rate of mass per second, therefore, would produce a steady-state flux condition. In order to work with a fixed flux reference, the contaminant flow-rate per second was used as a base. If this proves to be incorrect in later detailed analyses, the reference base can be readily shifted.

The area of the LTEP telescope tube aperture was calculated to be 0.00375 times the total area of the sphere which contains the aperture (Fig. A-11). A gross extrapolation indicates the cone volume shown (roughly the FOV volume) contains about 0.0038 times the total molecules in the ultimate dispersion-sphere of contaminants, the sphere having infinite radius.

In the case of the Independent LTEP, shown in Fig. A-12, the synthesized FOV volume is 0.0069 times the volume of the ultimate contaminant-dispersion sphere. Because the rate of contaminant emission is much less than for the Cluster, the latter was used as the limiting case for the study. The emission of the attitude control thrusters, although not necessarily random, was assumed to be so for the general analysis of molecule density and distribution around the spacecraft/telescope.

A.5.7.2 Effect of Spacecraft Orientation on Contaminant Flux. When the telescope LOS is perpendicular to, or pointing forward relative to, the orbit direction of flight, the total molecules or particles of contaminant in the telescope FOV will be as described in the preceding paragraph. However, as the LOS rotates toward an aft-pointing position, the FOV will include more and more molecules – those in the "trail" which has accumulated (see Fig. A-13). The total molecule quantity increase for full aft-pointing is estimated at least three times the quantity for the condition of forward pointing. A quantitative analysis of this increase should be done in follow-on studies.

A.5.7.3 The External Contaminant Flux. The primary external continuous-flux in fluence on the LTEP system operation will result from emission of gases or fluids from the AAP Cluster. The contaminants are listed in Table A-6. The total of these contaminants results in a steady-state condition with 18.7×10^{18} molecules in the field-of-view of the telescope with H_2O molecules a little over 50 percent of the total (this flux is increased as the LOS of the telescope is trained toward the "trail" and away from the direction of orbit flight).

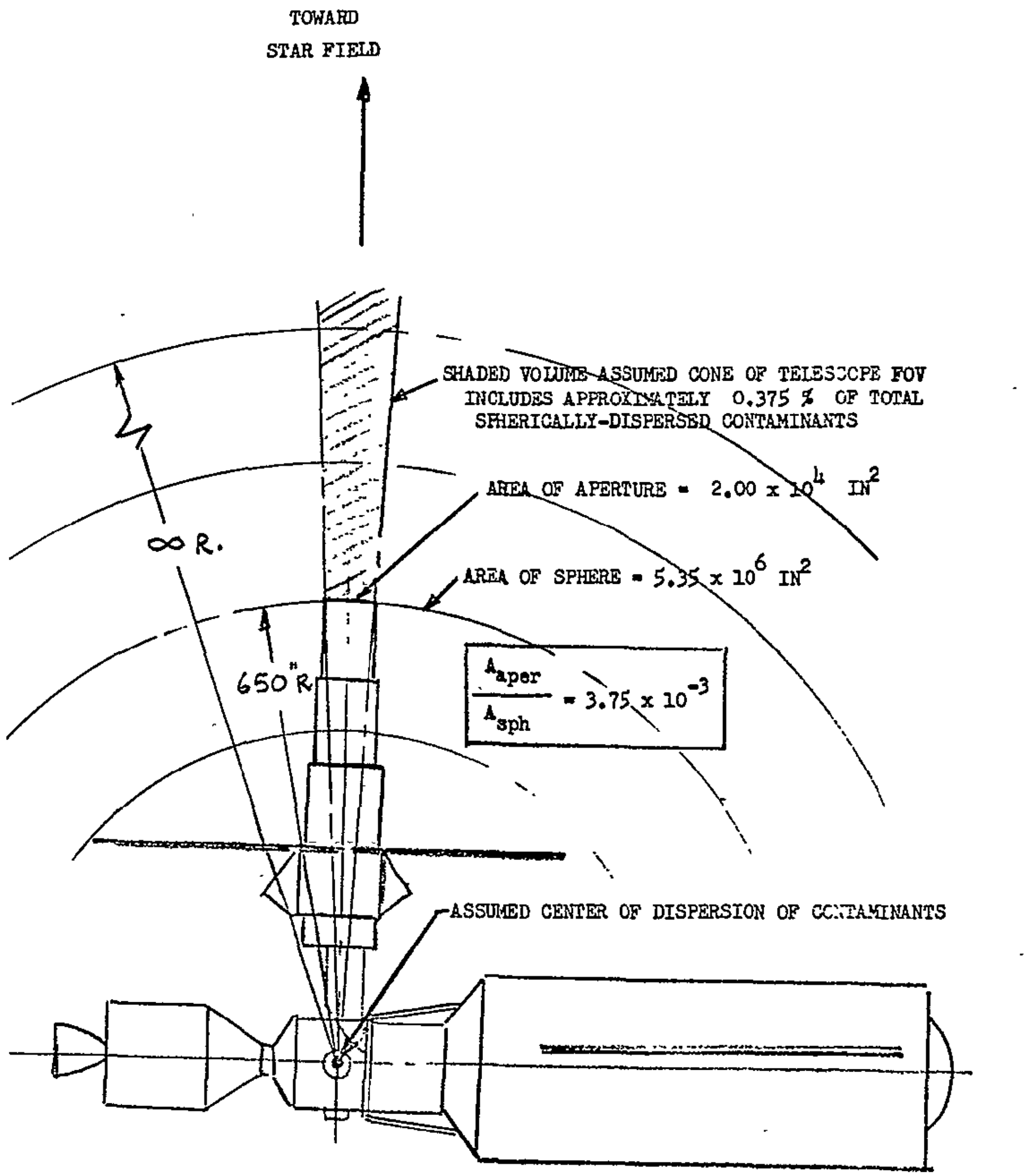


Fig. A-11 Percentage of Contaminants in Telescope Field of View – LTEP/AAP Cluster

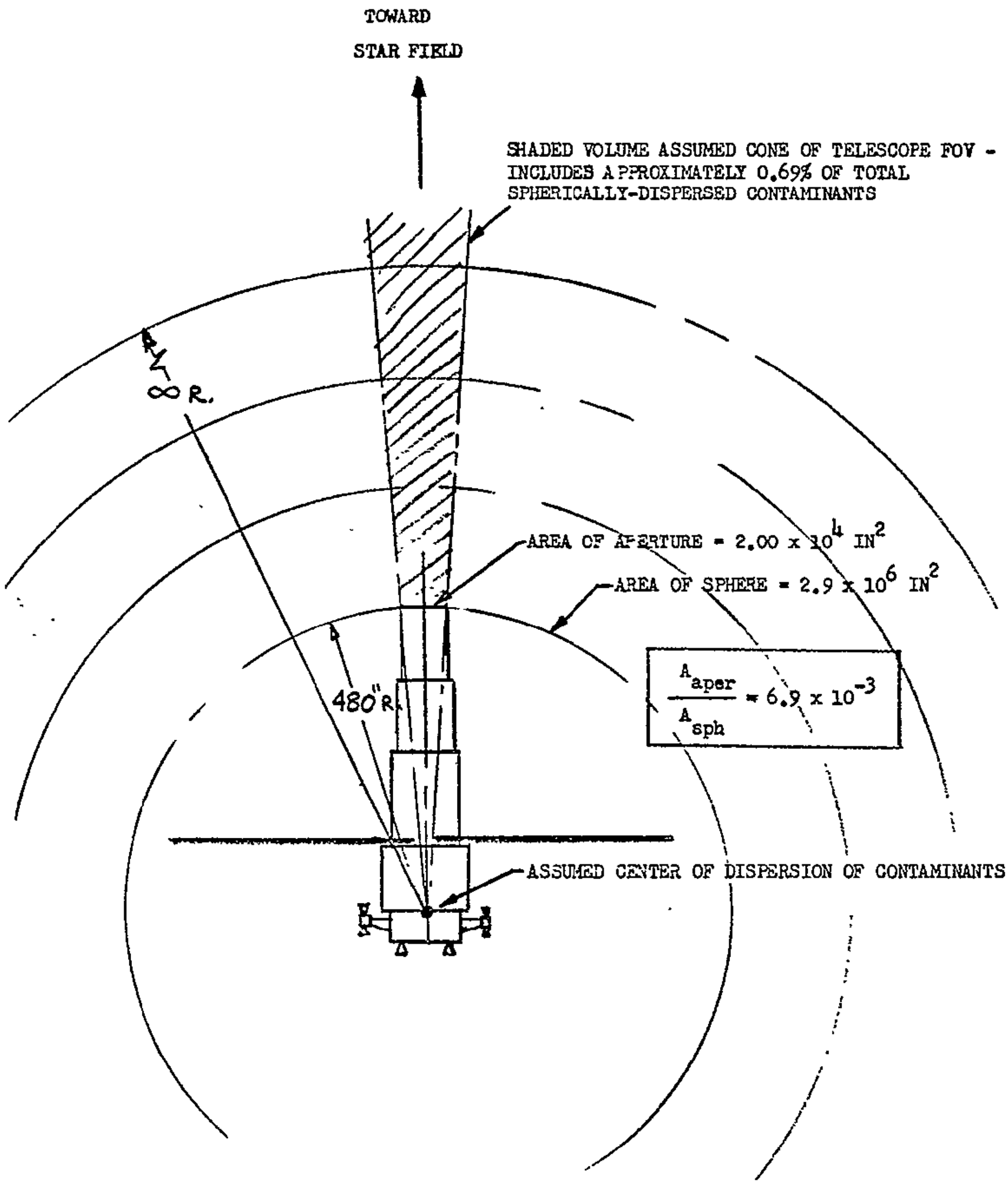


Fig. A-12 Percentage of Contaminants in Telescope Field of View – Independent LTEP

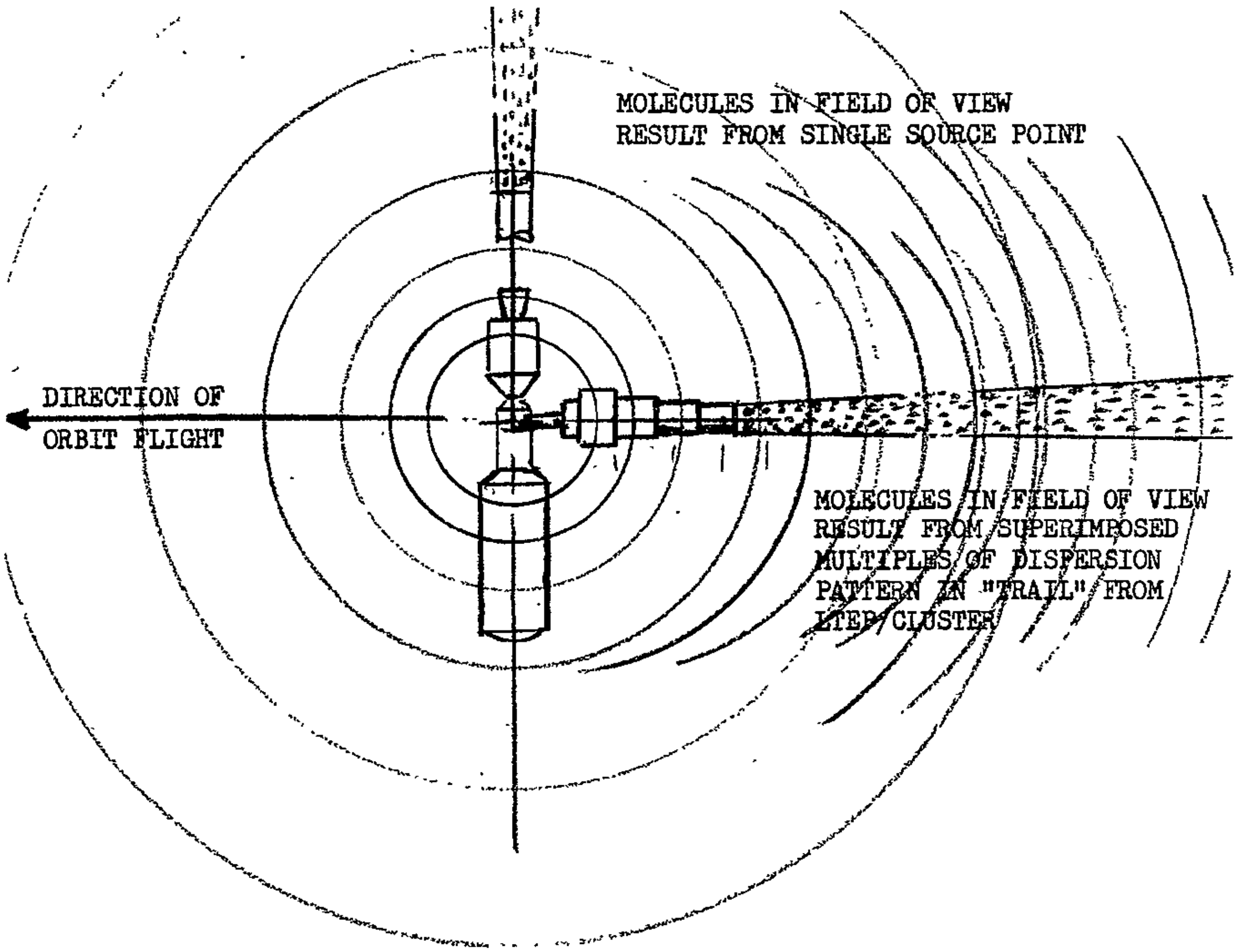


Fig. A-13 Increase of Molecules/Particles in Field of View With Aft-Pointing Telescope

Table A-6

BACKGROUND ILLUMINATION INTENSITY (CONTINUOUS) RESULTING FROM LIGHT SCATTERING BY CONTAMINANTS FROM AAP CLUSTER

Element	*Rate of Out-Gas or Vent	Weight of Molecule	Total Qty of Molecules Emitted (In One Second)	Molecules in Telescope FOV	Molecules Per sq cm	Background Illumination (From Scattering)
H_2O Leakage/Vent	0.075 g/sec	29.3×10^{-24} g	2.55×10^{21}	9.6×10^{18}	3.1×10^{14}	10^{-11} I_{sun}
O_2 Leakage/Vent	0.101 g/sec	52×10^{-24} g	1.94×10^{21}	7.3×10^{18}	2.3×10^{14}	8×10^{-12} I_{sun}
N_2 Leakage/Vent	0.0215 g/sec	46×10^{-24} g	0.47×10^{18}	1.8×10^{18}	0.6×10^{14}	10^{-12} I_{sun}
Totals	—	—	4.96×10^{21}	18.7×10^{18}	6.0×10^{14}	1.9×10^{-11}

*Note: Contaminants will tend to disperse from vicinity of spacecraft in approximately one second. A rate of emission of grams per second will therefore maintain a steady-state flux.

In the short time periods in which the attitude control thrusters are providing coarse-pointing maneuvering for stellar target acquisition, the thruster contaminant flux is as shown in Table A-7. The molecules in the telescope FOV total 8.67×10^{20} with H_2O molecules again comprising about 50 percent of the total. A small percentage (by weight) of uncombined liquid propellant molecules may be emitted from the thrusters as a result of start-up or shut-down conditions where the fuel and oxidizer are not completely combined or in special cases where the oxidizer is used as a nozzle-wall film coolant. These quantities have not been estimated; however their effect should be considered in analysis of surface degradation on solar arrays and sensor lenses.

A.5.7.4 The Internal Contaminant Flux. The internal-mounted optical surfaces of the telescope are the most critical elements in the LTEP system. Although quantitative analyses were not made, the following general analyses were made regarding the total flux of contaminants within the telescope tube.

a. By approximation, the thruster contaminant emission will result in a density of approximately 5.5×10^{-10} lb/ft^3 or 8.8×10^{-12} g/cm^3 at the telescope aperture, which is 650 inches from the source. (This is based on historical data which indicates that the density of emissions from a 100 lb thrust-level thruster was 26×10^{-8} lb/ft^3 at 180 inches from the nozzle.) It is assumed that this same pressure will be temporarily evident in the tube volume of 3.14×10^7 cubic centimeters; this would result in a total weight of 27.5×10^{-5} grams distributed throughout the volume of the tube.* Although the total thruster contaminant available to the aperture opening is 1.88×10^{-3} grams throughout a complete star acquisition maneuver (wherein 4 lbs of propellant are expended) it is assumed that the tube pressure will remain essentially constant at the 8.8×10^{-12} g/cm^3 density and that the total contaminant available for condensation/deposition within the tube would be the aforementioned 2.75×10^{-4} gram for each star acquisition cycle. The contaminants would comprise the percentages, weights, and molecular density shown in Table A-8.

   The aforementioned excludes the possibility that the density within the tube would be decreased by cold-plate collection of molecules, thereby reducing the optical cloud but possibly transferring the problem to one of contaminated surfaces.

   All of the foregoing is based upon the premise that the sun shield is open and allows gases to progress into the tube from the space outside the tube. Actually, the tube should be closed by the sun shield during use of the thrusters, thereby preventing these large amounts of contaminant from entering the tube. The data was presented to indicate the potential severity of the problem if the sun shield were to be open in the coarse acquisition mode.

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*Note: This is an extremely conservative extrapolation but it has been used for this illustration of the concept. At the conditions stated, the pressure at the aperture would be about 2×10^{-6} Torr for H_2O and the mean free path of molecules would be about 4 meters; flow into the tube would probably be governed by contact with the tube wall rather than by collision between molecules.

Table A-7

BACKGROUND ILLUMINATION INTENSITY (SHORT TIME TYPICAL) RESULTING FROM ATTITUDE CONTROL THRUSTER EMISSION FROM AAP CLUSTER

Element	Rate of Emission	Weight of Molecule	Total Qty of Molecules Emitted (In One Second)	Molecules in Telescope FOV	Molecules Per sq cm	Background Illumination (From Scattering)
H_2O (33 percent)	3.3 g/sec	29.3×10^{-24} g	112×10^{21}	4.20×10^{20}	1.34×10^{16}	4.3×10^{-10}
N_2 (40 percent)	4.0 g/sec	46×10^{-24} g	87×10^{21}	3.25×10^{20}	1.03×10^{16}	4.0×10^{-10}
CO_2 (16 percent)	1.6 g/sec	92×10^{-24} g	17×10^{21}	0.65×10^{20}	0.21×10^{16}	0.6×10^{-10}
CO (10 percent)	1.0 g/sec	66×10^{-24} g	15×10^{21}	0.57×10^{20}	0.18×10^{16}	0.5×10^{-10}
Totals	–	–	231×10^{21}	8.67×10^{20}	2.76×10^{16}	8.4×10^{-10}

Note: Maximum duration of thruster usage is 30 minutes for a 3-axis coarse-pointing maneuver for stellar field or star acquisition.

Table A-8

THRUSTER CONTAMINANTS WITHIN TELESCOPE TUBE FOR EACH STAR ACQUISITION CYCLE

Element	Amount	Weight	Molecular Density (Molecules per cm^3)
H_2O	33%	0.93×10^{-4} g	9.9×10^{10}
N_2	40%	1.10×10^{-4} g	7.7×10^{10}
CO_2	16%	0.44×10^{-4} g	1.52×10^{10}
CO	10%	0.28×10^{-4} g	1.33×10^{10}
Total		2.75×10^{-4} g	–

b. Outgassing of the materials within the tube cavity are assumed negligible (based on implementation of preventive approaches outlined in Section A.6).

c. The occurrence of dust particles, residual from telescope as-launched, within the tube cavity is a probability. No estimate has been made of the quantity but it should be negligible if proper precautions are taken in cleanliness during pre-flight phases and if the tube cavity is isolated from pyrotechnic device debris and other contaminant sources until after orbit erection of the telescope.

d. Drifting of contaminant particles into the tube from external sources will also probably occur. Although the sun shield will be closed and prevent entry into the tube of contaminants during launch, ascent, maneuvering, and coarse-pointing, materials deposited on the external surface of the sun shield or "floating" in the vehicle vicinity (residual from other parts of the vehicle) may be forced in by the kinetic energy of the previously-discussed molecular fluxes.

In the non-operating mode, the most severe potential impact of contaminants comes from the astronaut suit emissions in EVA. Whenever possible the telescope tube cavity should remain closed (closing the sun shield) during all EVA preparation (airlock module pressure dump, etc.) and during periods the astronauts are outside the Cluster man-cells. The primary-mirror access opening should be opened only for mandatory operations and then only for the minimum length of time consistent with inspection or other astronaut functions. Opening the sun shield during these periods creates no additional problem. The O_2 leakage from the space suits is of minimum importance. However, the rather heavy flux of H_2O molecules (or droplets) being emitted from the PLSS evaporative cooling loop is of primary concern because of the close proximity of the contaminant source to the optical surfaces. It may become necessary for the astronaut to carry a "cryogenic-plate"* for collecting H_2O vapor from the mirror prior to closing the access door to the primary-mirror compartment. The condition of the astronaut in the vicinity of the telescope aperture (with sun shield open) also will create a high-flux of H_2O molecules and the effects should be carefully analyzed in follow-on studies.

A.5.7.5 Effect of Contaminants on External Surfaces. The quantitative effect of the contaminant fluxes on externally-mounted sensor lenses, solar cells, thermal control surfaces, and antenna surfaces has not been analyzed; however, a qualitative analysis has been performed. In general, the various gases and pure water vapor create no foreseeable problem; it is assumed that they will be dispersed to space. However, corrosive fluids (such as uncombined propellants) may cause deterioration. These effects are predictable and quantitative values can be determined by analysis and/or by testing when the hardware concepts have been made more firm. This effort should be planned for Phase B.

Considering the large surface areas of the solar arrays and the thermal control surfaces, no problem is anticipated because the deposition of solid particles (dust and pyrotechnic device debris) if reasonable precautions are taken in design approaches and fabrication. This will include consideration of use of shielding on plumes and vent outlets and implementation of super-clean fabrication and assembly techniques.

Perhaps the most critical of any external surfaces subject to deterioration by contaminant deposition are small sensor lenses, such as the star sensor to be used for coarse-pointing control reference. There are current NASA efforts to establish the degradation potential to instruments such as sun sensors, and star sensors. Previous tests have indicated that transmission of UV and visible light though a glass lens can be reduced up to 20 percent as non-metallic contaminants are deposited on the lens surface and the deposit approaches 1.3×10^{-3} grams per cm^2. A deposit of 10^2 grams per cm^2 makes the lens opaque. The results of an LMSC test (Reference 7-8) are summarized in Fig. A-14. This test employed a solid-propellant motor (with aluminum-oxide solids in the exhaust) and a gas-generator (with sodium-carbonate solids in the exhaust). The results are not directly pertinent to the LTEP problem, but are presented to illustrate a test and analytical approach to establishing quantitative data on contaminant flux effects. Similar test and analysis can be accomplished on a bi-propellant thruster system as planned for LTEP.

*Note: This collector device conceptually comprises a heater for vaporizing any deposited water and an encircling chilling ring for recollecting the vapor on the device. The device would be moved slowly across the surface manually with a rod extension.

A.5.7.6 Telescope FOV Light Scattering and Absorption. Because precise stellar-pointing is not being accomplished during coarse-acquisition maneuvering with the attitude-control thrusters, the thruster emission has been omitted from the steady-state stellar-viewing consideration. Table A-6 shows the total quantity of molecules stacked in the telescope FOV as equal to 6.0×10^{14} per cm^2 of aperture opening. This will provide a background illuminance of approximately 1.9×10^{-11} I_{sun}. This compares with the intensity of a 12th magnitude star which is 2.16×10^{-4} I_{sun}* (Reference 7-25). It is less than the light scattered from the earth atmosphere at approximately 200 nm, which is 1.3×10^{-10} I_{sun}. From these data, it may be assumed that there will be no major problem with background illuminance caused by sunlight scattering of the combined earth atmosphere and LTEP system outgassing/venting molecules. Even if it were assumed the contaminants remained in a cloud around the spacecraft for 100 seconds instead of 1 second, wherein the molecules per cm^2 would increase to 6.0×10^{16} and the intensity to approximately 6×10^{-10} I_{sun}, the resulting relative intensity of the contaminant back-glow would be over 10^5 less than the 12th magnitude star intensity.

A cursory inspection of light absorption reveales that for 900 Angstrom wavelength, the number of molecules, N, in the FOV should equal approximately 2×10^{14} x area of aperture (in cm^2) to produce a 2 percent light absorption (Reference 7-25). For the LTEP telescope, this equals approximately 6×10^{18} molecules. With the steady-state contaminant flux, there will be 18.7×10^{18} molecules in the LTEP FOV (from Table A- 6).

Table A- 9 (below) shows the light absorption for various quantities of molecules in the telescope FOV.

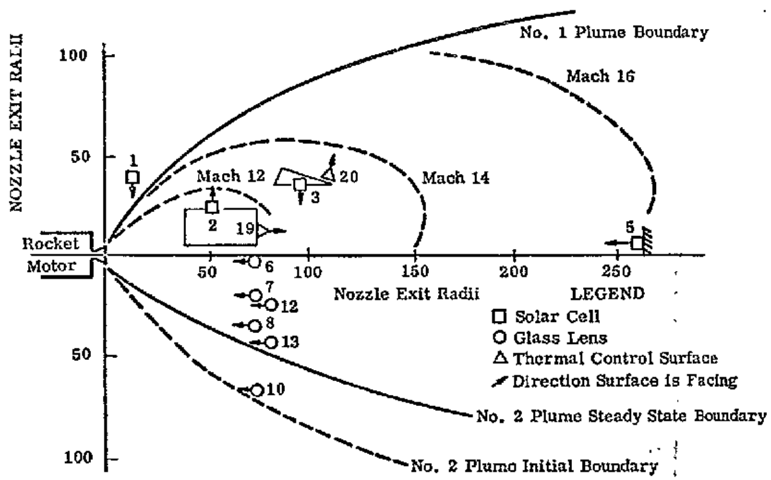
Table A-9

MOLECULES IN FOV VERSUS LIGHT ABSORPTION

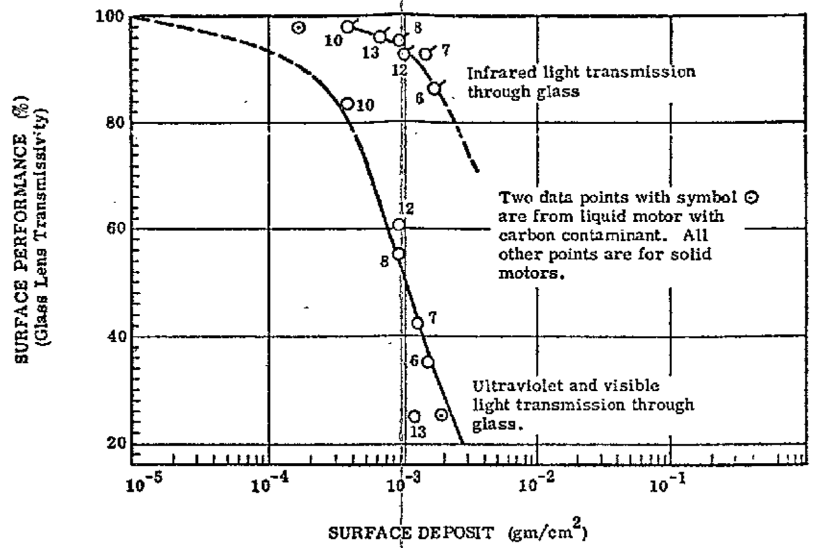
Number of Molecules in Front of Telescope With 2-Meter Aperture	Percentage of Light Absorption (%)
6.0×10^{18}	2.0
8.4×10^{18}	2.8
1.0×10^{19}	3.5
2.1×10^{19}	6.85
4.2×10^{19}	13.15
Note: Data extrapolated from Reference 7-25	

*Note: Intensity per unit area in the focal plane of an astronomical telescope with 200 cm focal length and 60 cm aperture diameter at wavelength of 1000 Angstrom.

LMSC PLUME-SURFACE CONTAMINATION TEST CONFIGURATIONS



CONTAMINATION EFFECTS ON SURFACE PERFORMANCE



MOTOR	NO. 1 PLUME TEST	NO. 2 PLUME TEST
Chamber Pressure	2200	2500 psia
Chamber Temperature	4620	2660°R
Burn Time	0.7	1.0 sec
NOZZLE		
Area Ratio	14	26
Exit Radius	0.650	0.363 in.
EXHAUST	$0.25\%\ Al_2O_{3(s)}$	$0.30\%\ Na_2CO_{3(s)}$
Species Content	CO, CO_2H_2O, HCl	CO, CO_2, H_2O, N_2
Specific Heats Ratio	1.24	1.26
SIMULATED ALTITUDE		
Initial	300,000	300,000 ft
Steady State	200,000	250,000 ft

The sketch indicates the location and orientation of surface specimens in rocket motor plumes tested by LMSC.

The plot shows the effects of plume contamination on the transmission of light through lenses. Performance plots for solar cells and thermal control surfaces are similar.

The number inside each symbol on the plot identifies the location of the test surface on the sketch.

Fig. A-14 Results of LMSC Test – Deposition of Exhaust Products on Exterior Spacecraft Surfaces

FOLDOUT FRAME 1

FOLDOUT FRAME 2

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It appears that there will be light absorption of about 3 percent in the LTEP system resulting from gas molecules stacked in the telescope FOV.

The foregoing discussion on absorption of light applies to conditions where molecules and particles are one micron or less in size. Agglomeration of H_2O molecules into droplets, if occurring, would alter the analytical approach. Further quantitative analysis and testing is needed in this area.

A.5.7.8 Effect of Contaminants on Internal Surfaces of Telescope. The presence of gases (O_2, N_2, CO_2, CO) in the telescope cavity will create no deterioration of surfaces. The gas molecules upon striking a surface will rebound or eventually be re-released from the surface unless there is a chemical-reaction or absorption into the surface (as may occur with O_2). With the steady-state flux at the tube aperture, the tube will probably remain "filled" with these gases during the stellar-pointing periods when the sun shield is open.

The contaminant of primary concern is H_2O or other fluids in the vapor-phase. These will probably deposit on the relatively colder internal surfaces of the telescope.* Some of all of the liquid may evaporate, leaving the surface clean. With the steady-state supply of water vapor, however, it is presumed that a certain quantity will remain on the optical surfaces in a state of equilibrium. The amount of water vapor in the tube, assuming no replenishment from outside the tube (believed a reasonable assumption if there is a pressure balance between the tube cavity and the ambient volume just exterior to the aperture); is approximately 0.93×10^{-4} grams (from Table A-8). Detailed analysis and tests to determine the water vapor equilibrium condition on the optical surfaces at various temperatures are beyond the scope of this study but should be an important part of follow-on effort in Phase B.

The condensation of water vapor on the other (black specular coated) surfaces within the telescope tube does not appear to cause significant change in thermal characteristics (although this has not been analyzed). If condensation or deposition-out of water vapor or other liquid is found to be significant in follow-on analysis, a recheck should be made of the specific effect on thermal balances within the tube.

The potential collection of urine solid particles on optical surfaces is estimated to be insignificant. The total of 3.45×10^{-7} lb/sec emission results in an estimated 6×10^{-7} gram/sec flux in the telescope FOV (assuming a spherical dispersion pattern similar to the gases). Because the particles have little energy of their own, they will probably not disperse as quickly nor as far from the Cluster as the gases. They will tend to be swept "aft" (re: direction of orbit flight) by the impact of the molecules/atoms in the ambient space environment. Only those particles which are "pushed" by the out-flowing gas-molecule flux or which have combined with the water-vapor droplets will be moved to the aperture of the telescope. Local pressures at this tube opening may tend to force a very small quantity of these particles into the tube.

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*Note: The tube internal pressure, on the order of 10^{-6} Torr, is less than the vapor pressure of solid H_2O at 200°K, which is 6.14×10^{-3} Torr. Ice crystals probably will not form on the internal surfaces.

Quantitative analysis and investigation of the urine solid characteristics and flow-patterns is necessary in follow-on effort.

A.6 CONCLUSIONS – OUTGASSING CONCEPT

A.6.1 General Conclusions

The following conclusions have been drawn from the study. In Sections A-6.2 and 6.3 respectively specific conclusions on materials selection and spacecraft configuration and operation relevant to minimizing contaminants and effects thereof are presented.

A.6.1.1 The Contaminant Emissions. A significant quantity of gases and vapors will be emitted from the AAP Cluster. The emission from the attitude control thrusters occurs only at the beginning of a stellar-pointing period and is of concern primarily in considering deterioration of external surfaces: lenses, solar cells, thermal-control surfaces, and antenna surfaces. The sun shield preferably should be closed during this thrusting period to prevent entry of the contaminants into the telescope cavity.

The emissions from the man-cells of the Cluster are significant, contributing to light-scattering and absorption and to potential deposition on telescope internal surfaces and optics. They comprise O_2 , N_2 gases and water vapor; the number of H_2O molecules is about 50 percent of the total.

Battery venting (from the CSM only) consists of gases and water vapor but is insignificant in quantity relative to the Cluster emission total.

The emissions from the life-support packs (PLSS) of astronauts during EVA inspection or maintenance of the telescope are significant, not because of the amount of emission, but because of their close proximity to the optical surface (primary mirror) when an adjacent access door is opened for visual inspection or other operation. During these operations, the access should be opened a minimum of time and external contaminant sources should be at a minimum (no attitude control thrusting and no venting from man cells).

The urine water dumping is included as part of the total H_2O emission from the Cluster. The potential of solid contaminants (salts, etc.) being emitted along with the water vapor in the hot-plate vaporizing process must be more thoroughly investigated. The weight of the contaminants is small but the average flux extended over the many days of the LTEP mission is sufficient to cause primary mirror contamination problems.

No specific estimation was done on the quantity of outgassing materials within the telescope cavity. This will be required after preliminary material selections have been made in Phase B.

A.6.1.2 Contaminant Effects on LTEP System. Assuming that the thrusters are located properly to minimize close-range impingement of exhaust plumes, no serious surface damage will result. There are no solids in the bi-propellant thrusters and small amounts of corrosive uncombined fuel or oxidizer (due to start-up, shut-down, or leakage) should disperse readily in the ambient vacuum prior to droplet deposition on any surfaces. The probability of and quantity of uncombined propellant emission must be rechecked subsequent to the preliminary selection of thruster hardware.

The initial primary effect of emissions from the Cluster is the collection of molecules in the telescope field-of-view, thereby causing:

a. Background illumination from sunlight scattering on the molecules

b. Light absorption by the stacked molecules

The background illumination has far less, by 10^{-5}, relative intensity than a 12th magnitude star and is not believed to be a problem. There will be light absorption by the stack of molecules in the FOV approaching 3 percent.

The secondary deteriorating effect of Cluster emissions is the potential deposition of water vapor onto the internal surfaces of the telescope cavity, particularly the optical surfaces. The equilibrium of this gas/liquid/crystal system on the cold-plate type surfaces must be thoroughly analyzed and tested in follow-on effort (Phase B).

The potential is minimal for outgassing of materials within the telescope cavity if preventive measures listed in Section A-6.2 are implemented. A recent test by LMSC (for NASA/Langley) on a 1.5 inch diameter (scaled down from the full-size 10-inch diameter) gold-coated radiometer mirror in vacuum simulating 500 km altitude, indicated no sublimation (or outgassing) from black-anodized aluminum or from 3M black paint mounted adjacent to the mirror in the test chamber. The parts had been baked in a vacuum for 4 hours at 165°F before the test. This type of test must be accomplished on any materials in the LTEP system which are located within the telescope tube cavity or near a sensor lens.

The flux of solid dust particles was not estimated. However, use of precautionary approaches in vehicle design and emphasis on fabrication cleanliness should minimize the probability of a major problem in this area. The most important operating preventive measure will be to keep the telescope sealed at all times with the sun shield prior to the initial stellar-field sighting.

In astronaut EVA operation, the emission from the suit life-support packs is not significant unless the astronaut is near the open end of the telescope tube or near an open access door in the area of the primary mirror (mirror inspection or replacement). Flaking-off of exterior space-suit particles is assumed not to be a problem if current suit coverings can be modified to exhibit a smooth coating (non-flaking) to the surrounding environment (current suit covering is a fiberglas base which tends to flake-off small particles somewhat readily). A more detailed analysis is necessary in this area after EVA modes are firmed up and the maximum tolerable types/amounts of gases and particles in the tube cavity and on the optical surfaces have been established.

A.6.2 Materials Selection

The proper choice and processing of materials for the internal telescope cavity is of special importance to control of deteriorating outgassing. Any outgassing contaminants can be readily drawn to the optical surfaces and permanently deposited; this is potentially the most critical of the various contaminant effects. The following are the minimum precautions which should be taken in implementing the LTEP system hardware, primarily that within the telescope cavity:

a. Carefully review all materials relevant to stability in vacuum at various temperatures (ambient ground and test temperatures as well as orbit operational).

b. Specifically test any material upon which specific data is not available to determine the thermal-vacuum stability and degree of outgassing.

c. Avoid the use of any organic materials.

d. Use metals or inorganic materials or other essentially inert materials, in lieu of elastomers, for seals, etc.

e. Do not use grease or fluid lubricants; use solid-type lubricants preferably those which can be coated onto or impregnated into metal surfaces.

f. Do not use potentially-subliming metals (even in alloy form) such as zinc or cadmium. Use magnesium alloys only after precise assessment of long-term vacuum stability at the operating temperature.

g. In processing, follow all plating, coating, or bonding operations with a high-temperature vacuum baking period to sublime or evaporate all volatiles, residual water, or unpolymerized non-metals. (Even conversion coatings such as anodizing on aluminum have residual water entrapped as result of the solution treatments.)

h. Do not use absorbent nor hygroscopic materials.

i. Use clean-room assembly and test conditions to assure a minimum of dust particles in delivered hardware.

j. Provide covering and sealing of the telescope tube cavity during all shipping and prelaunch handling.

A.6.3 Vehicle Configuration and Operation Constraints

Certain basic approaches in the design of the LTEP system hardware will aid in minimizing contamination effects.

a. Position thrusters so plumes do not impinge on critical surfaces at close-range. Place thrusters as far from critical surfaces as possible.

b. Provide a loose-fit labyrinth seal on the sun shield periphery to prevent direct entry of contaminants during lid-closed operation.

c. Avoid areas of rubbing or sliding contact in the telescope cavity (to reduce the possibility of debris).

d. Avoid, where possible the use of mechanisms which cause vibration or shock, thereby lessening the possibility of loosening residual particles

e. Isolate pyrotechnic devices from the telescope cavity and where possible, confine the debris from pyrotechnic device activation.

f. Provide the sequence-control for the sun shield to remain closed during all ascent erection, and coarse-pointing maneuvering to prevent entry of contaminants.

g. Avoid any semi-closed cavities which could trap particles or water vapor (which would later be released in orbital vacuum).

h. Isolate the telescope cavity containing optical surfaces from the remainder of optical subsystem equipment where possible. The open aperture end should be the only unsealed opening to the cavity.

i. Include a minimum quantity (preferably none) of electrical devices or cabling within the telescope cavity. Overloads and heating can cause severe outgassing problems (failure mode).

A.7 RECOMMENDATIONS

A.7.1 Follow-On Analyses

It is proposed that the following list of candidates be used in establishing studies for the anticipated Phase B program. (They are not necessarily listed in the order of suggested priority.)

a. Further study the layering of contaminants of varying densities in the telescope field-of-view and determine the degree of light refraction and star image scintillation.

b. Determine potential chemical reactions of incident gases and other contaminants in the telescope cavity with the optical surfaces.

c. Determine the urine solids content type and quantity vaporized overboard by the AAP Cluster and estimate its flow patterns in dispersal in the vicinity of the LTEP/Cluster.

d. Determine quantitatively the kinds and amounts of solid exhaust and debris from pyrotechnic devices planned for AAP Cluster/LTEP operation and estimate dispersion patterns, probable deposition areas, and approximate deposition worst-case thickness.

e. Carefully review all organic materials intended for use on the LTEP system and assess their vacuum characteristics. Determine their approximate out-gassing products and rates.

f. Investigate potential of modification to astronaut space suit covering to eliminate current flaking-off of fiberglas particles.

g. Determine the approximate composition of the "trail" of contaminants behind the orbiting spacecraft/LTEP telescope and assess the viewing characteristics when the telescope LOS is pointed through this mass.

h. Determine possible quantities of uncombined fuel or oxidizer which may be emitted from bi-propellant thrusters during typical thrusting or dormant (leakage) cycle. Estimate the characteristic of dispersion in the vacuum near the LTEP/Cluster, both in the thrusting mode and the non-thrusting mode (latter for leakage only).

i. Perform analysis of astronaut PLSS and space-suit emissions and the probable effect on close-proximity to primary mirror and at end of telescope.

j. Perform quantitative analysis on the effects of various contaminants on externally-mounted solar arrays, sensor lenses, antenna surfaces, and thermal control surfaces. Particular emphasis should be placed on corrosive particles or liquids such as uncombined propellant or urine solids with water vapor.

k. Determine by analysis and/or test the equilibrium condition of water vapor on simulated cold-plate telescope tube interior and adjacent optical surfaces. Assess preferential deposition of particles.

l. Perform quantitative analysis of the effect on thermal characteristics and thermal balances within the telescope tube as a result of water vapor condensation or ice crystals formation.

A.7.2 Special Design Concepts

Two specific areas have been identified for possible further conceptual design and analysis effort. On the basis that condensation of vapors upon or deposition of particles upon the primary mirror surface is perhaps the most serious problem confronting the implementation of the LTEP system, and presuming that no reasonable external control will reduce the contaminants to a level tolerable to the mirror, it is proposed that:

a. A study be initiated to determine the feasibility and functional efficiency of a cold-plate "trap" that can be installed in the telescope cavity in the vicinity of the critical optical surfaces (multiple units possible). This device would collect and hold all contaminants making contact with the plate, thereby reducing the flux available to the optical surfaces. Methods for periodically cleaning the plate would also be investigated.

b. A corollary study be initiated, using the same principle, to conceptually develop a device which could be carried by the astronaut in EVA and either automatically collect suit and PLSS emissions or could be manipulated by the astronaut in cleaning the primary mirror after close-proximity inspection (not touching the surface).

Both of the devices could be used in conjunction with vaporizing processes which, potentially, could be implemented periodically by automatic heating of the optical surfaces and thereby impart energy to previously-deposited molecules, essentially driving them away from the optical surfaces and toward the cold-plate collector.

A.7.3 Test Programs

Specific test programs that could be initiated with current facilities should be considered for early Phase B effort. Among these could be the following analysis/test efforts.

a. A specific study and testing program to determine the deposition products on various LTEP critical surfaces and the effects of bipropellant thrusters (one of the main contaminant sources in the LTEP system):

   (1) Calculate the thruster outputs

   (2) Calculate the plume (computer program)

   (3) Calculate the plume impingement and flux at various critical surfaces (computer program)

   (4) Determine the sticking coefficients (capture characteristics of the various optical surfaces)

   (5) Determine surface deposition (by actual test of models)

   (6) Determine equivalent transmissibility losses of surfaces for various wavelengths of energy (UV/visible/IR).

b. An actual test of scattering, refraction, absorption, etc., of the LTEP environment utilizing various gases and particles injected into a vacuum chamber through which light beams of varying intensity would be passed. LMSC has a Solar Illumination Simulation Facility which creates, within a fixed test volume, an excellent approximation of the photometric environment as found in space. This facility could be used for such a test.

APPENDIX B

ORBIT MECHANICS PARAMETERS

This appendix presents a discussion of certain aspects of the orbit mechanics for the LTEP mission. The reference orbit is circular at 220 nm altitude with an inclination of 35 deg, which is the orbit currently planned for the AAP Cluster with the solar telescope (SWS-I).

B.1 ANGLE BETWEEN ORBIT PLANE AND SPACECRAFT SUN-LINE

The reference orbit will have a regression of the right ascension of the ascending node at the rate of 6.57 deg/day inertially, or 7.56 deg/day with respect to the earth-sun line, completing one revolution with respect to the sun every 47.6 days. This will cause the angle between the sun line and the orbit plane (α) to vary between 0 and 58.44 deg. The expression for this angle is:

$$\sin \alpha = \sin i \cos \delta \quad \sin \Delta\lambda + \sin \delta \quad \cos i$$

where:

- i = orbit inclination
- δ = declination of sun
- $\Delta\lambda$ = difference between right ascension of sun and ascending node.

A time history of this angle is given in Figure B-1 for an assumed right ascension of the ascending node of 180 deg at time $T = 0$ measured from a solstice.

B.2 SPACECRAFT-SUN ANGLE

For the LTEP vehicle in an inertially-fixed orientation, as will be the case during astronomical observations, the angles between a spacecraft-fixed coordinate system and the sun line will remain relatively constant over the course of several revolutions. In fact, if a given spacecraft orientation is held for more than a day the primary variation in these angles is due to the earth's motion around the sun which is at a mean rate of 0.9856 deg/day. Limiting values on the sun angles are established by the constraint that the telescope must not point within 45 deg of the spacecraft-sun line.

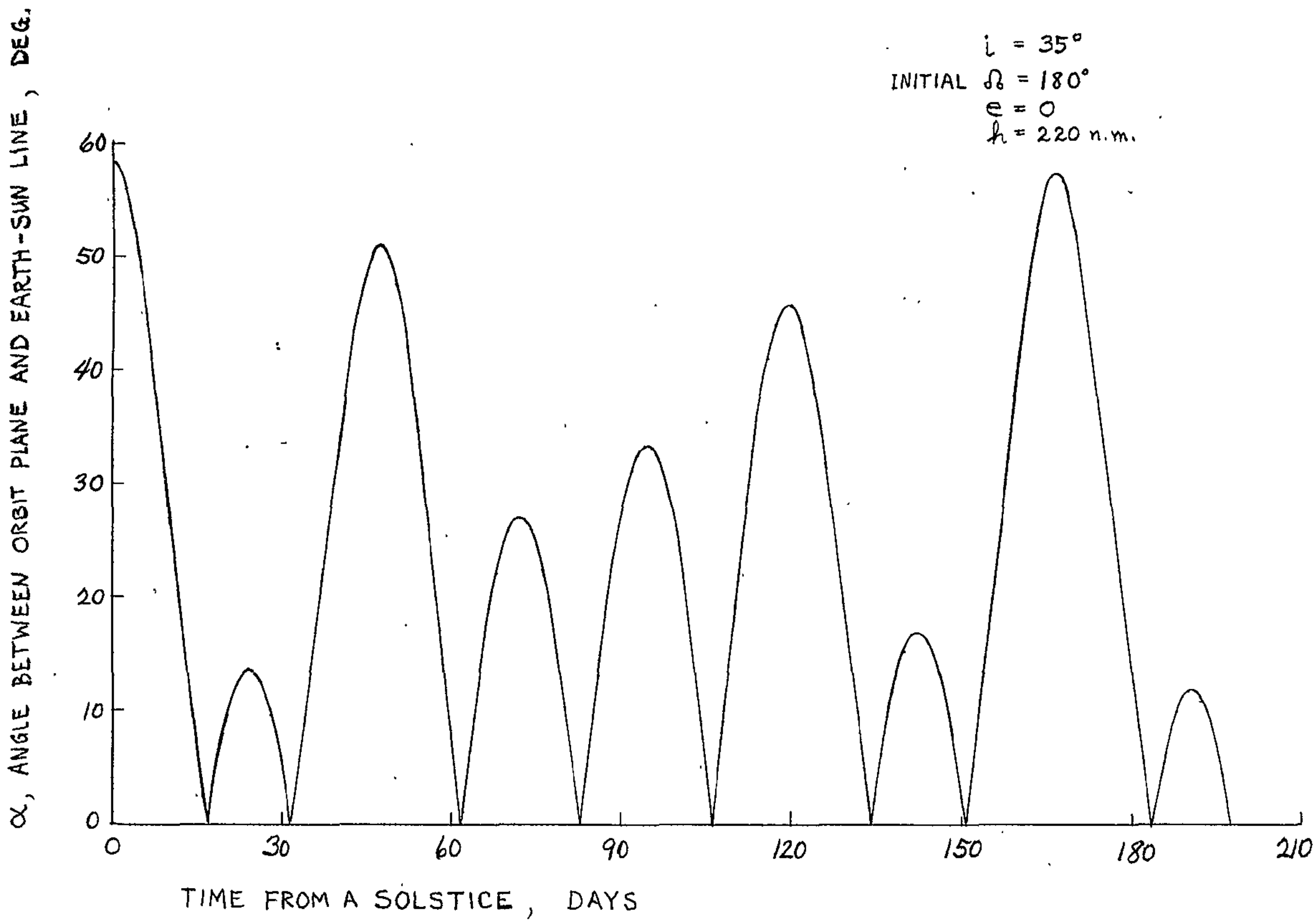

Fig. B-1 LTEP – Angle Between Orbit Plane and Sun Line

B.3 OCCULTATION

The time the spacecraft will spend in the earth's shadow (or solar occultation time) will vary between 25.35 and 36.1 minutes per revolution for a circular orbit at 220 nm inclined 35 deg. As shown in Figure B-2, the duration is a function of the angle between the orbit plane and the earth-sun line, α, the history of which was shown in Figure B-1. The maximum possible value of the angle α is 58.5 deg, occurring at the summer or winter solstice.

The time spent in the earth's shadow by the spacecraft is given as a percentage in Figure B-3 as a function of time from a solstice. The same initial nodal orientation is assumed as for Figure B-1, producing the minimum possible occultation time at T = 0. The maximum is reached each time $\alpha = 0$, or every 23.8 days on the average.

For any given astronomical target the earth will occult the LTEP view at least during the course of one nodal cycle (54.8 days) since to have an uninterrupted view of even a small portion of the celestial sphere the orbit altitude would have to be above 480 nm for inclinations of 28.5 deg or greater. For most targets the earth occultation will occur daily. The maximum duration of occultation of any astronomical target for a circular orbit at 220 nm is also the 36.1 minutes per revolution shown in Figure B-2, and this could occur for any target with a declination equal to or less than the orbital inclination. The minimum occultation time is a function of the target declination and the orbit nodal orientation with respect to the target. There is an uninterrupted view over the course of a revolution in the regions within approximately 20 deg of the orbit normal (northern and southern hemispheres).

B.4 ORBIT DRAG DECAY AND ORBIT MAINTENANCE

If the requirement is to stay above 210 nm for the mission duration, as is the case for the AAP Cluster with the solar telescope, a thrust impulse of 35 ft/sec will be required approximately every 118 days for the LTEP operating in the independent mode. This is based upon a near-minimum solar activity, as is predicted for 1974-75 with a conservatism to cover the prediction uncertainties for that period. An estimated nominal time between maneuvers for this period is 200 days and an M/C_DA of 8.53 lb/ft^2.

One significant problem associated with the spacecraft operation beyond the 2-year required lifetime is the orbit maintenance during a period of high solar activity. The next solar maximum is expected to occur in 1979. The atmospheric density increase at 220 nm due to the high electromagnetic radiation could require that the interval between orbit maintenance maneuvers be as frequent as every 16 days. This, however, is still not conservative, since the density could be additionally increased by the possibly-associated large corpusular component of the solar energy, in which case the orbit maneuvers could be required every 8 days. The LTEP propellant capacity of 2100 lb usable propellant is substantially greater than that required for the first two years of operation, which is estimated at 700 lb. However, within the ten year desired life, the high frequency of maneuvers could require a resupply interval as small as 5-1/2 months to one year. Alternatives to such frequent resupply are: (1) at some point, perhaps immediately after commencement of independent operation, to use some of the propulsion capability to raise the orbital altitude to a much higher altitude, such as 300 nm, or (2) set the initial orbit altitude much higher.

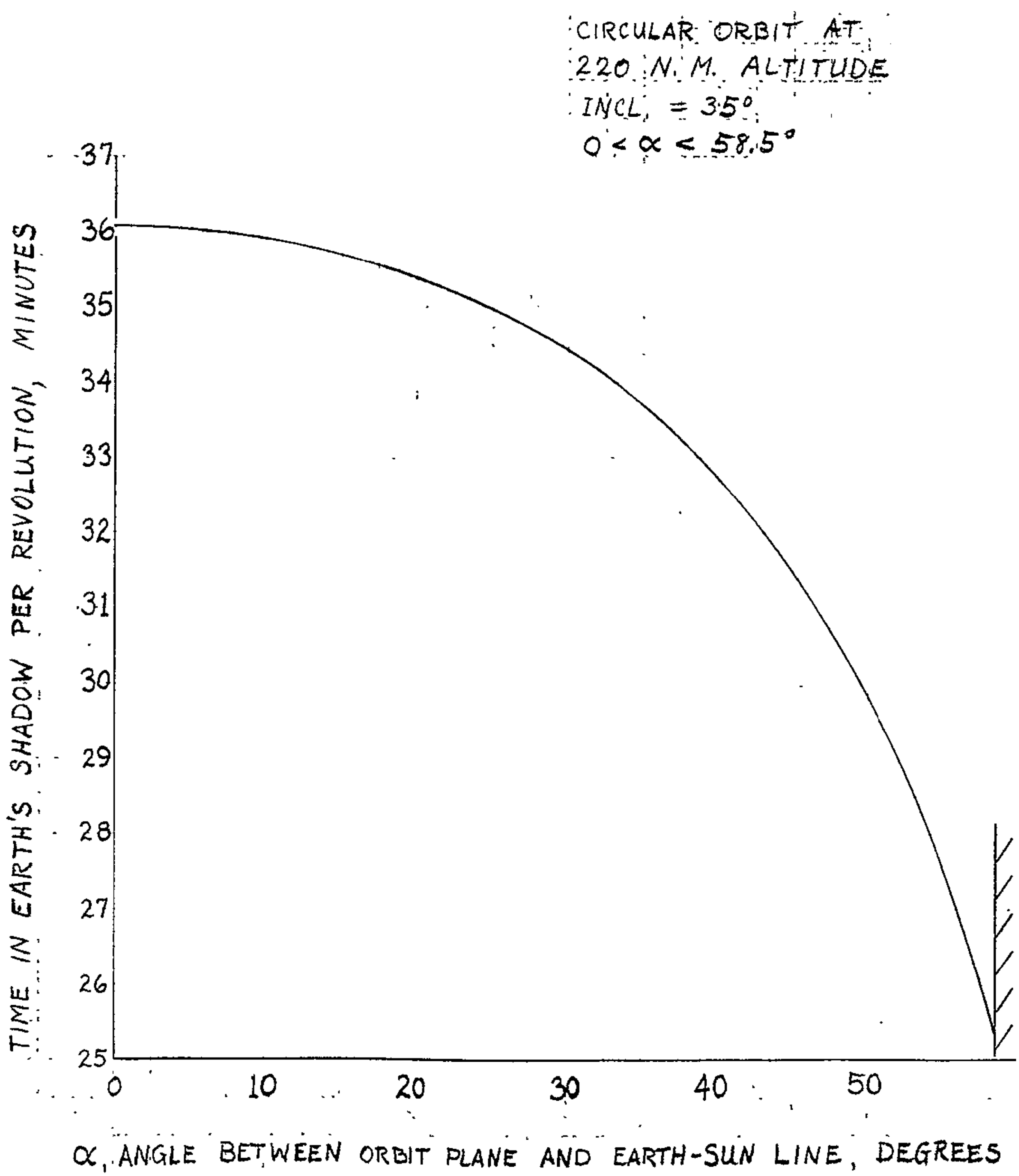

Fig. B-2 LTEP – Solar Occultation Time

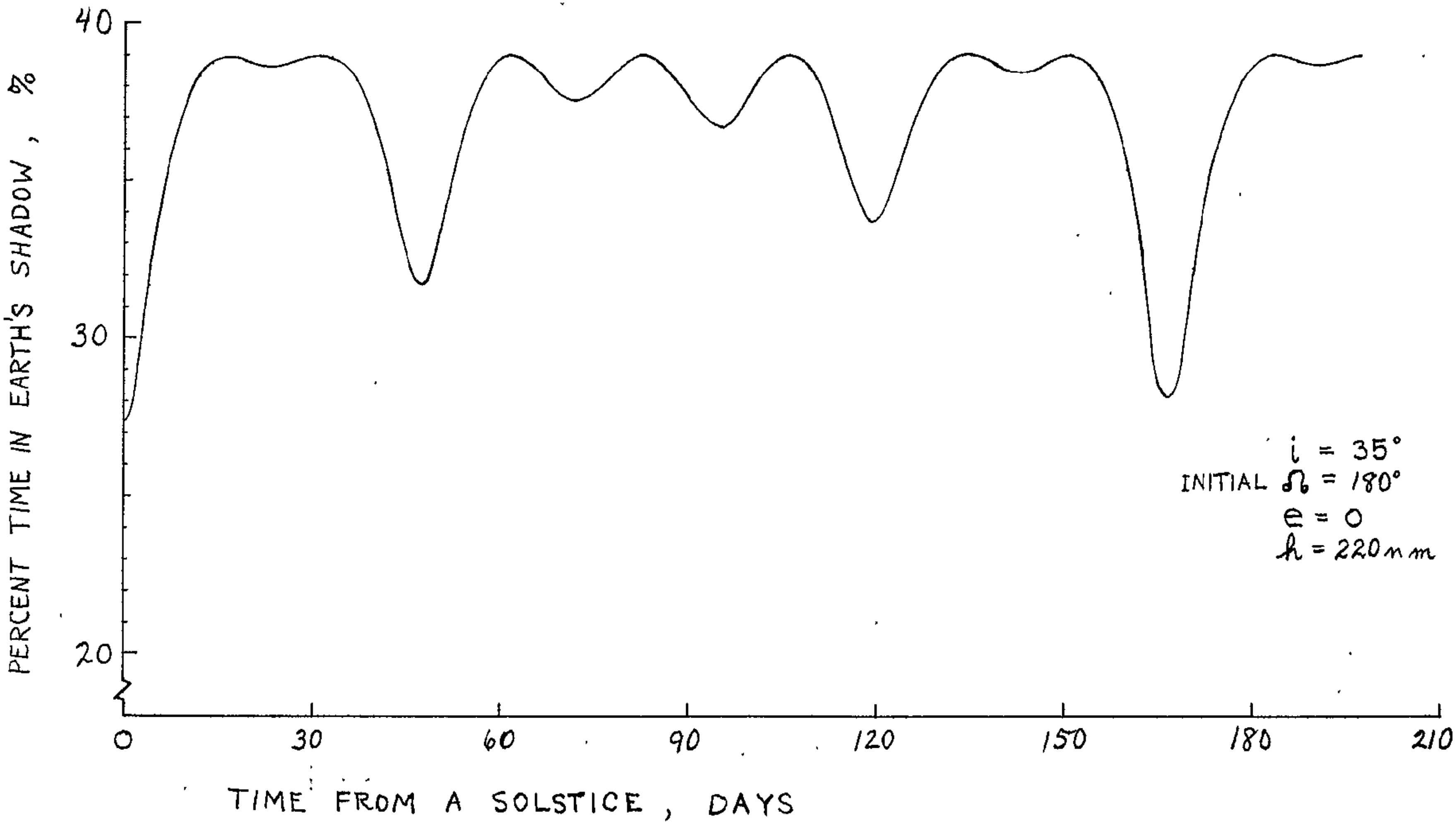

Fig. B-3 LTEP – Spacecraft Time in Earth's Shadow

APPENDIX C

LTEP ELECTRICAL POWER REQUIREMENTS

C.1 OBJECTIVE

The objective of the LTEP electrical power requirement analyses was to establish the electrical power requirements for the LTEP system, evaluate the potentially-available hardware elements, and develop a conceptual design of electrical subsystems for both the AAP Cluster-attached and the Independent operational modes.

C.2 SCOPE

The study covered the following elements:

a. Establishment of orbit restraints affecting the use of solar arrays and determination of basic power requirements for LTEP.

b. Review of NASA/MSFC data on the electrical system of the AAP Dry Workshop, including details of solar arrays.

c. Determination of solar array positioning requirements for LTEP stellar pointing and modifications to SIVB and ATM solar arrays to accommodate the LTEP.

d. Conceptual design of the Independent LTEP electrical subsystem.

e. Conceptual design of the AAP Cluster/LTEP electrical system.

The results of initial analyses made (Reference 7-11) were reviewed relevant to the current LTEP system requirements for electrical power and the recently-issued NASA/MSFC data on the AAP Dry Workshop (Reference 7-22).

An updated electrical subsystem has been conceptually developed. The electrical power requirements for the LTEP system were determined, both for the AAP Cluster-attached and Independent operating modes.

The current AAP Dry Workshop Cluster electrical system was examined to determine its adaptability for use with the LTEP system. A combined Cluster/LTEP electrical system was conceptually developed. The characteristics of the AAP Cluster electrical components were reviewed and units selected for use with the Independent LTEP system. The LTEP electrical system operating characteristics and element weights were determined.

C.3 RESULTS

C.3.1 LTEP Electrical Subsystem Operational Requirements

The applicable mission requirements, orbit restrictions, and basic power requirements for the LTEP missions are described below.

C.3.1.1 Mission Requirements. The LTEP system will operate, either Cluster-attached or Independent, at 220 nm altitude with an orbit inclination of 35 deg out of the ETR. The spacecraft/telescope, after acquisition of a stellar target, will remain inertially stabilized in one position for continuous viewing of that target (except for earth-occluded periods).

The LTEP system is to operate for a 2-year continuous period with extension to 10 years utilizing resupply/maintenance/replacement.

The system is to fly in CY 1974 or 75, i.e., a flight scheduled to be "piggy-back" on the second AAP Dry Workshop Cluster (launched on the Saturn V derivatives (the S1C stage plus the SII stage). An Independent launch on the Saturn IB (S1B stage plus SIVB stage) or the Titan IIIC are possible alternate modes.

The LTEP electrical subsystem must be compatible with the AAP Cluster system during the attached mode and must be self-dependent after separation from the Cluster.

C.3.1.2 Orbit Restrictions and Solar Array Movement. The LTEP telescope must point to any target in the universe except that the line-of-sight may not intersect a cone generated about the earth-sun line with a 45 deg half-angle (Fig. C-1). After acquisition of the stellar field, the spacecraft/telescope will remain locked-on (inertially stabilized) to the target for periods from a few hours to about four days (multi-orbits).

The orbit plane of the LTEP system will be rotating relative to the sun line at a rate of about 7.56 deg per day, completing a 360 deg rotation cycle in 360/7.56 = 47.6 days. The angle of the sun with the orbit plane will vary from 58.5 deg to zero in about 12 days, from zero to -11.5 deg in the next 12 days, back to zero in 12 days, and then back to 58.5 deg in 12 days (complete cycle = 47.6 days).

The spacecraft/telescope, although in the orbit plane, will have a fixed inertial position relevant to the sun during a single stellar-pointing period and therefore, will present a single solar array orientation during this period. Alignment of solar arrays with the sun, if required, will be accomplished prior to extra-fine optical pointing (to prevent torque disturbances during steady-state stellar viewing).

During the cycling of the orbit-plane angle with the sun line from zero to 58.5 deg, the time per orbit that the LTEP system is in earth's shadow varies from 25 minutes (for zero angle) to 36 minutes (for maximum angle); Fig. C-2 contains a curve showing occultation time. The worst case, 36 minutes, has been chosen as the time that no sun energy would be available to the LTEP system solar arrays.

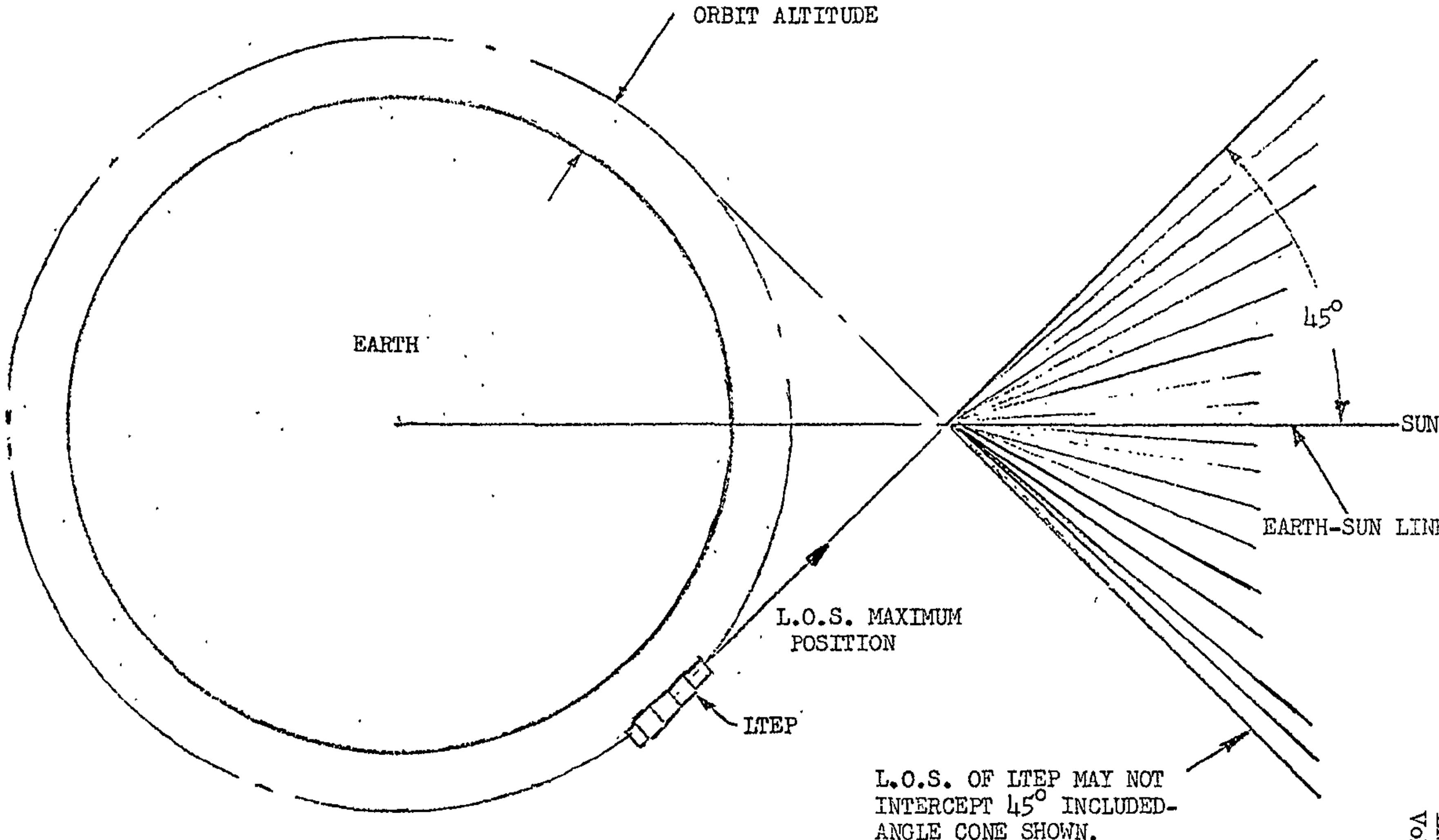

Fig. C-1 Viewing Limits of LTEP

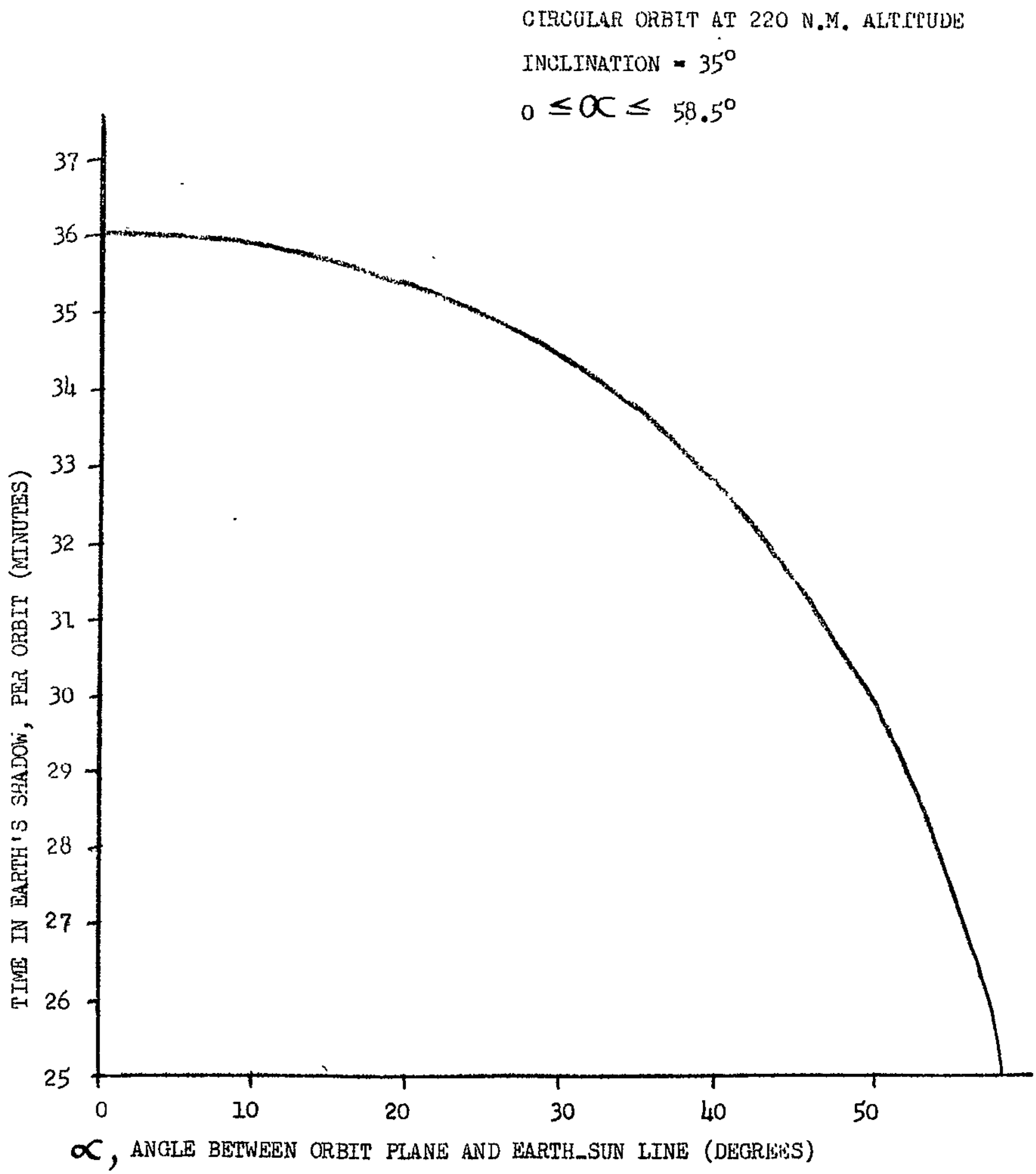

Fig. C-2 Solar Occultation Time per Orbit

C.3.1.3 Basic Power Required for LTEP System. The continuous average power required for Independent operation of the LTEP Module has been estimated to be:

CMG's	800 Watts
Telescope	250
LTEP subsystems (communications, data processing, control, propulsion)	450
Contingency	200
Total	1700 Watts

The power requirements for the main user, the CMG's, (from Reference 7-22) are:

	Per CMG	Total
Bearing heaters (warmup) (-60°F to 50°F)	240 W	720 W
Bearing heaters (run) (50°F to 70°F)	48	144
Inertia-wheel runup (9 hours max.)	170	510
Inertia-wheel steady-state	56	168

The warmup bearing heaters are turned on prior to energizing inertia wheel drive; these require 720 watts input. The run bearing heaters are cut in when the temperature has raised to 50°F and are intermittently switched on or off to maintain bearing temperature in the range of 50°F to 70°F. Simultaneously, the inertia-wheel runup motors are energized; they require an average 510 watts. Total required during the runup is therefore 144 + 510 = 654 watts. After the runup period (9 hours maximum) the steady-state load drops to 144 + 168 = 312 watts. It can be seen that the 800 watts initial power for the CMG's is conservative and, in later system refinement and optimization, can probably be lowered and provide additional margins for telescope and spacecraft subsystem power.

The power for operating optical system elements was set at 250 watts, utilizing an earlier estimate. This number will require firming up in follow-on study as the electrical load profiles for optical system and experiment support become available.

The estimate of 450 watts for support of the LTEP various spacecraft subsystems is conservative. During stabilized periods of stellar-pointing, "maintenance" power will possibly drop to as low as 200 watts. As the various subsystems are firmed-up during preliminary design, refined estimates of spacecraft subsystem electrical power will be required.

C.3.1.4 Operational versus Standby Power Requirements. With the telescope loads, except the heaters, in a dormant state; with CMG's and Pointing Control System (in ATM Rack) holding a prescribed inertial position in orbit, and with other LTEP subsystems dormant (except for a communications link for ground station tracking), the estimated electrical loads are:

CMG's (inertia-wheel steady-state)	168 Watts
CMG Bearing Heaters (run-intermittent)	144
Telescope	20
LTEP Subsystems	200
Contingency	100
Total dormant	632 Watts

This "dormant" total wattage required is considerably lower than the 1700 watts which has been selected as the operational average for the system. During system optimization studies reduction of the operational power may be desirable; using battery power exclusively for early peak loads may allow reducing the solar array size. Each of the solar arrays has five segments; removal of one or two segments can probably be accomplished without significant influence on the other parts of the system. Any reduction of this type in available solar array power should be delayed until all LTEP electrical loads have become relatively firm.

C.3.2 Current AAP Cluster Electrical System

Because compatibility with the AAP Cluster is a primary requirement for the LTEP system, a rather complete survey of the newly-proposed Dry Workshop electrical power system (EPS) was made, using data in Reference 7-22 as well as information from direct contact with NASA/MSFC. The system is described following. The modifications required for the LTEP system application are discussed separately in Section C.3.4.

C.3.2.1 AAP Cluster Electrical System Description. The Saturn V Workshop EPS comprises the (1) ATM solar array/battery system, (2) the Orbital Workshop/Airlock Module (OWS/AM) solar array/battery system, and (3) the associated control and distribution networks. A simplified block diagram is shown on Fig. C-3.

The OWS/AM electrical system supplies 3700 watts average from two solar arrays of 600 ft^2 each and eight power conditioning groups, each comprising a battery charger, a bus voltage regulator, and a battery. Lifetime of this system is being increased to 9 months (was rated 2 months).

The ATM electrical system supplies 3480 watts average from 4 solar arrays of 300 ft^2 each and 18 charger/battery/regulator modules (CBRM's). Lifetime of the system is being extended to 9 months (from 2 months). The ATM power system supplies redundant power to ATM loads simultaneously through diode isolation so that single-point failure will not prevent normal operation of any load package. A bidirectional power transfer up to 2500 watts can be made between OWS/AM and ATM power systems for contingency operations.

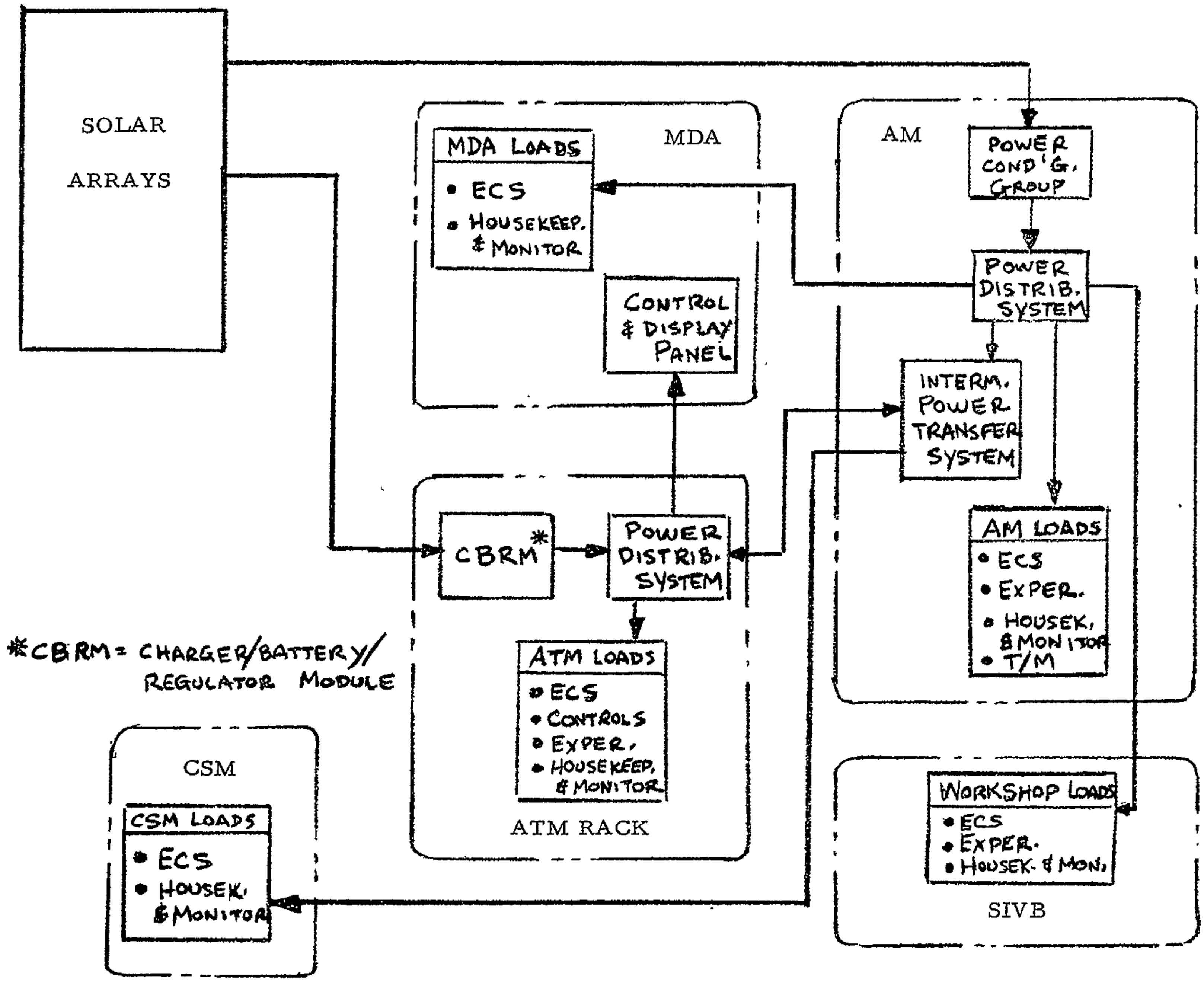

Fig. C-3 Block Diagram of Electrical Power System – Saturn V Workshop Cluster

C.3.2.2 Electrical Loads and Capability. The electrical loads for the previous Saturn I Workshop (SIWS) and the new Saturn V Workshop (SVWS) are tabulated on Table C-1. The ATM electrical system capability (3480 watts) exceeds the load by 1083 watts.

The Workshop/AM system has a negative margin of 75 watts, due to an increase of dormant CSM electrical load to 1100 watts (from a previous 450 watts). This higher wattage for the "dormant" CSM is a conservative estimate of the power required to keep the CSM in a "semi-ready" status and allow shutdown of the CSM fuel cells (previously supplying 1800 watts).

C.3.2.3 Solar Array Configuration. Figure C-4 is an illustration of the orbit configuration of the AAP Dry Workshop Cluster. There are two solar array wings on the SIVB and four solar array wings on the ATM Rack; the latter are oriented at 45 deg to the long axis of the cluster.

Figure C-5 is a scale drawing of the Cluster/ATM showing the relative size and location of the solar arrays. The four arrays on the ATM are extended to a fixed position as shown. The OWS solar arrays are stowed in longitudinal fairings on the SIVB cylinder during launch and ascent and are unfolded after orbit position has been attained. Initially planned for rotation about a forward hinge axis as shown, these two arrays will be locked in the central position for the Dry Workshop Cluster operation with the ATM (it has been indicated that the rotating mechanism can be reinstalled in the Dry Workshop).

Each ATM array consists of five, approximately 8 feet square segments; each panel in the array is 20 x 24.6 inches. The OWS arrays are about 313 inches in the fore aft direction and are stowed in fairings, each of which is 13 x 48 x 397 inches long. The OWS array panel size is 27.1 x 30.1 inches.

C.3.2.4 Cluster Solar Array Characteristics. Table C-2 lists the characteristics of the ATM and OWS solar arrays. A change has been made to the OWS solar cell and cover glass from an initial 0.012-inch thick silica (fused-quartz) to a 0.006-inch thick "standard" glass; the changes reduced the potential life capability of the cells from 24 months to 9 months. The ATM solar cells are the higher-performance type and have an estimated life in excess of 24 months. The primary degradation of the micro-glass cover results from darkening because of UV exposure (estimated to be about 5% to 10% degradation in a 9-month period).

The ATM arrays are conservatively-sized for the loads involved. An LMSC calculation indicates that a solar array end-of-life output to satisfy the ATM electrical system requirements would be sized to output approximately 6.6 KW; the NASA array equivalent output is 10.6 KW (for 4 wings). Because this value assumes a solar cell degradation of about 10 percent, it is probable that this array could operate for an additional four years with an additional accumulative 10 percent degradation. In other words, the arrays (4) would output approximately 9.5 KW at the end of 5 years (paragraph 3.3.3 d.).

Table C-1

ELECTRICAL LOAD SUMMARY – SATURN I VS SATURN V CLUSTER

System Element	Watts	
	SIWS	SVWS
OWS (load)	1866	1509
AM (load)	858	966
MDA (load)	200	200
CSM (load)	450	1100*
Subtotal	3374	3775
OWS/AM Electrical System Capability	3700	3700
Power Margin	326	(-75)
ATM (load)	3000	2127
MDA (ATM control display only) (load)	–	270
Subtotal	3000	2397
ATM Electrical System Capability	3480	3480
Power Margin	480	1083
Overall Cluster Power Margin	806	1008

*The CSM load (1100 watts) may be divided between the ATM and the OWS/AM power supplies.

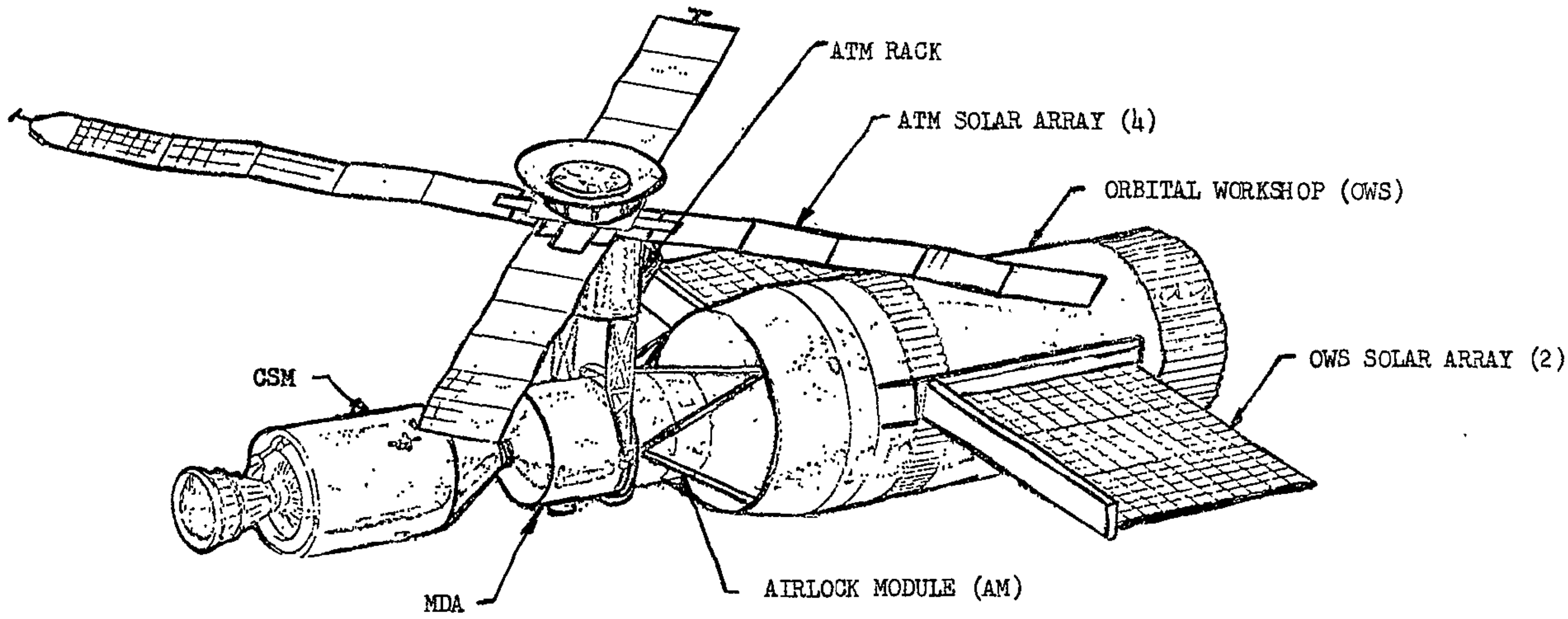

Fig. C-4 Orbit Configuration of AAP Dry Workshop Cluster (Saturn V Cluster)

Table C-2

CHARACTERISTICS OF ATM AND OWS SOLAR ARRAYS

Characteristic	ATM Solar Array	OWS Solar Array
• Area	1200 ft^2	1200 ft^2
• Weight (approx.)	3800 lb	3800 lb
• Honeycomb Panel		
Skin	0.015 in	0.008 in
Core (honeycomb)	3.1 lb/ft^3	3.1 lb/ft^3
Panel thickness	0.5 in	0.38 in
• Cover glass (for cell)	0.012 in silica (fused quartz)	0.006 in micro sheet (bottle glass)
• Watts/lb (solar panel)	6 watts/lb	11 watts/lb
• Normal incident output (at end of estimated life)	10.6 KW	11.9 KW
• Solar Cell		
Efficiency	9.8 minimum (10.25 avg.)	10.3 minimum (10.6 avg.)
Base material	10 ohm cm	1 ohm cm
• Panel operating voltage	38 volts	49 volts
• Array articulation	none	1 axis
• Life	*9 months (required) *24 months (actual)	9 months (actual)

*0.012 inch cover glass plus 10 ohm cell has estimated life expectancy of 24 months or longer. Current AAP Cluster requirement is 9 months for both ATM and OWS solar arrays.

C.3.2.5 Cluster Battery Characteristics. The ATM electrical power supply includes 18 batteries mounted on the ATM Rack. Each battery is rated at 20 ampere-hours, has 24 cells, and outputs a nominal 38 volts dc. General Electric is the battery supplier.

The OWS/AM electrical power supply includes eight batteries mounted in the AM; each rated at 33 ampere-hours, having 30 cells, and outputting a nominal 49 volts dc. Eagle-Picher is the supplier.

Both battery types have a life expectancy over two years with anticipated discharge cycling. (The discharge depth maximum is limited to 30% - well within the expected operating limits of both the AAP Cluster and the Independent LTEP.)

C.3.3 The LTEP Electrical Power Subsystem

Following an analysis of power requirements versus alternative system concepts for the Cluster/LTEP and the Independent LTEP systems, it was concluded that:

a. A solar-array/battery system provides the most reliable approach.

b. Fixed solar arrays, although feasible for the LTEP, would add a tremendous amount of weight to the system (multiple quantities of existing arrays). They would not be feasible for the OWS solar arrays because of array mechanical overlap and vehicle/array shadowing.

c. Single-axis movable arrays for both the LTEP and the Cluster, combined with rotation of the Cluster/LTEP or LTEP around the telescope line-of-sight, provides universal aiming of the solar arrays and allows positioning of array surfaces normal to sun-line coincident with any stellar-pointing attitude.

d. Placement of solar cells on both sides of solar arrays would increase weight of the arrays. Conversely, rotating each array ±180 deg in lieu of ±90 deg would allow use of single-side solar cell application.

e. Electrical loads estimated are satisfied by the use of two ATM solar array wings (in lieu of the present four) and the existing two OWS solar array wings.

The following are study results leading to the aforelisted conclusions.

C.3.3.1 LTEP Power Summary. The electrical loads to be supported by the Independent LTEP power subsystem are:

CMG's		800 watts
Telescope		250
LTEP Subsystems		450
Contingency		200
	Total	1700 watts

These can be supported by 2 ATM solar arrays, coupled with nine of the current 18 total ATM batteries.

Operation in the Cluster-attached mode reduces the LTEP subsystem loads to approximately 200 watts and the total ATM system load to 1350 watts (see Section C-3.4.1).

C.3.3.2 Solar Array Evaluation. The current OWS solar arrays (2-coupled with batteries) have an average output requirement of 3700 watts at end of life (9 months). This includes factors of battery efficiency, line losses, earth shading, and 10 deg misalignment of solar arrays (away from plane normal to sun-line).

Similarly, the ATM solar arrays (4) and associated batteries have an output requirement of an average 3480 watts at end of life (9 months) including all aforementioned reduction factors. These ATM arrays were initially designed for 24 month operation and can probably attain this with the same degradation percentage. If a very conservative approach were taken, however, a further 10% reduction could be assigned, reducing the net average output for a two-array system from 1740 watts to 1560 watts. This would in turn reduce the load contingency of 200 watts to 60 watts.

The following solar array approaches were inspected:

a. Current OWS Solar Arrays. The "fixed" position of the AAP Dry Workshop arrays is not compatible with LTEP operation. Using earlier existing single-axis rotation mechanisms, and rotating arrays ±90 deg from the neutral position, approximately 50 percent of the stellar universe would be available (maintaining arrays normal to the sun-line) if the Cluster/LTEP were also rotated about the telescope line-of-sight to aim the arrays. This hemispherical universe would be on the sun side of earth and be further restricted by the reduction due to the 90 deg block-out cone about the sun-earth line.

b. OWS Array With Solar Cells Both Sides. Full-universe viewing is possible if solar cells are placed front and back on the ±90 deg pivoting OWS arrays (cells are on sun side only now) and the Cluster/LTEP were rotated about the telescope line-of-sight for array aiming. Considerable array weight increase would result.

c. OWS Array with 360 deg Single-Axis Rotation. If the existing OWS arrays were rotatable ±180 deg from the neutral position and the Cluster/LTEP were rotated about the telescope line-of-sight for array aiming, full-universe stellar viewing is possible with no change in array (except rotation device modification).

d. ATM Array-Planar Fixed Position. Use of the existing ATM arrays in a fixed position with all surfaces in a single plane is not compatible with LTEP operations.

e. ATM Arrays with Single-Axis 360 deg Rotation. Utilizing the current ATM arrays, which in plan form are each 45 deg from the longitudinal centerline of the Cluster (see Fig. C-5) and rotating 360 deg about an array centerline hinge, one set of arrays (2) are frequently on edge relative to the sun line or in the shadow of the two arrays closest to the sun. In general, an output wattage reduction of 65 percent would result in the worst case.

It was concluded, therefore, that two of the arrays could be removed and the remaining two could be repositioned with the axial centerlines of the arrays 90 deg to the longitudinal centerline of the Cluster. With this configuration (shown in Fig. C-6), the two ATM arrays (and batteries) can output 1740 watts if the Cluster/LTEP is rotated about the telescope line-of-sight to aim the arrays and the arrays are rotatable 360 deg about their hinge axes.

C.3.3.3 LTEP Electrical System Description. The basic system will comprise primarily components of the ATM Rack electrical system. It will have an average output of 1740 watts, nominally at 38 volts dc. It will utilize two of the current four ATM solar arrays and nine of the current 18 batteries of the ATM system. A block diagram of the system is shown on Fig. C-7. The special features of the system are described following.

a. Solar Arrays. The solar arrays are identical to those used on the Apollo ATM Rack. Each array is approximately 105 inches wide and 525 inches long in the displayed position and comprises five segments. The two arrays are 180 deg opposed as shown in Fig. C-8. The stowed package size for each array is approximately 8 ft x 8 ft x 1 ft. The current extension mechanism is considered adequate. A minor modification is required at the inboard end of each array to adapt it to the newly-added rotation mechanism.

   A 360 deg rotation mechanism is required on each array at the attachment to the top frame of the ATM Rack. The centerline of rotation would be perpendicular to and intersecting the centerline (line-of-sight) of the telescope. All actuation of the arrays for alignment with the sun-line will be accomplished after coarse-pointing stellar target acquisition and prior to steady-state optical pointing. The array rotation, coupled with rotation of the LTEP vehicle about the telescope line-of-sight, will provide solar array aiming at the sun-line for any orientation of the vehicle.

   The ATM solar array weight (1020 lb per wing or 300 ft^2) is heavier than equivalent state-of-the-art roll-out arrays. The higher weight is currently tolerable with the launch vehicle capability, however, and the advantage of multi-usage of Apollo equipment accrues. If later missions require reduced launch weights, the total array weight can probably be reduced about 40 percent.

   The solar arrays for the LTEP system must have a maximum output at end-of-life (at least 2 years) of 3240 watts; 1500 watts allocated to battery recharge and 1740 watts to electrical loads. The existing ATM arrays (2) are rated at 5300 watts output at end of nine months. Conservatively, subtracting 15 percent for additional solar cell degradation, it appears that the ATM arrays could still quite adequately support the LTEP system (5300 x 0.85 = 4500 watts) for periods up to five years or more.

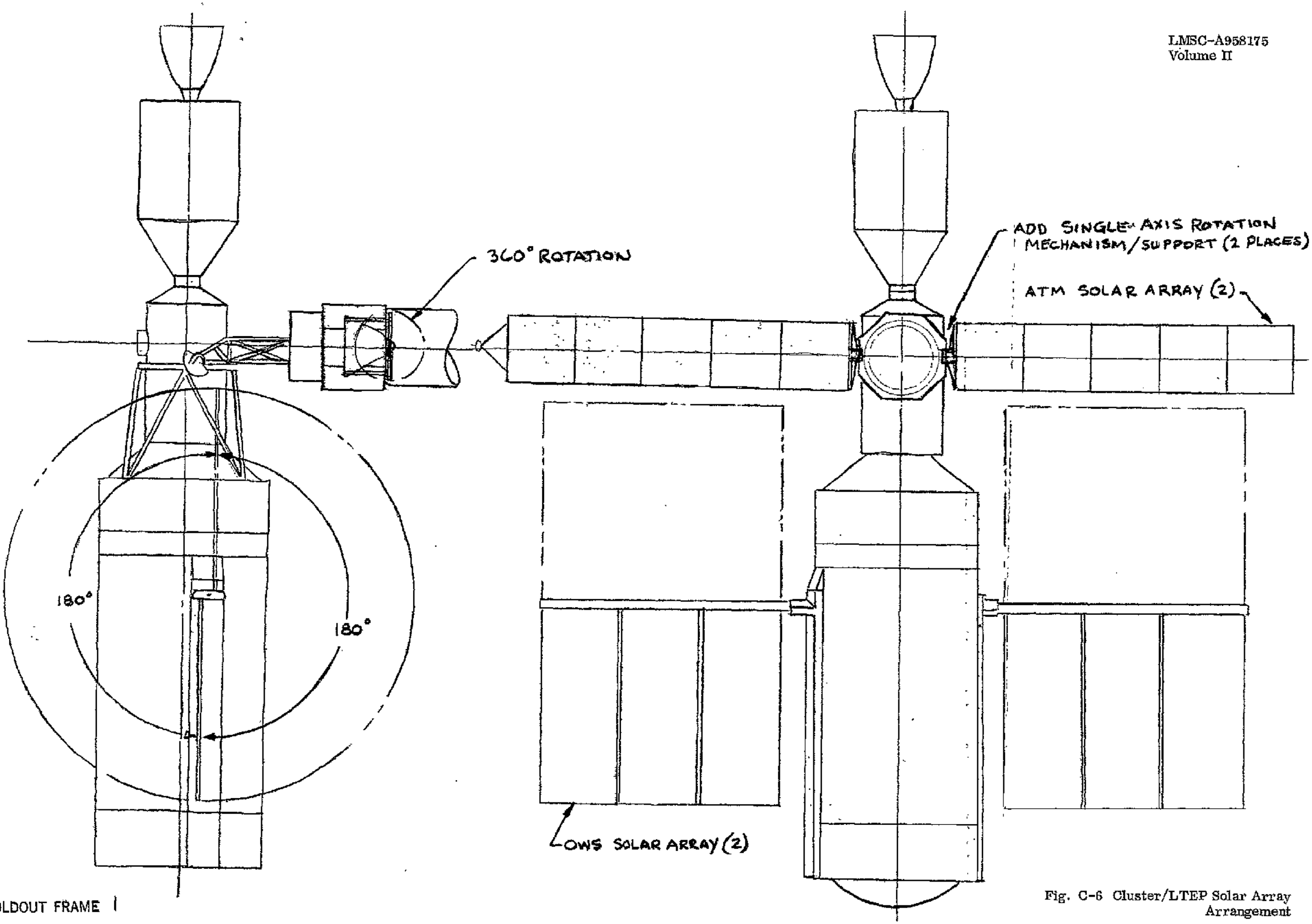

Fig. C-6 Cluster/LTEP Solar Array Arrangement

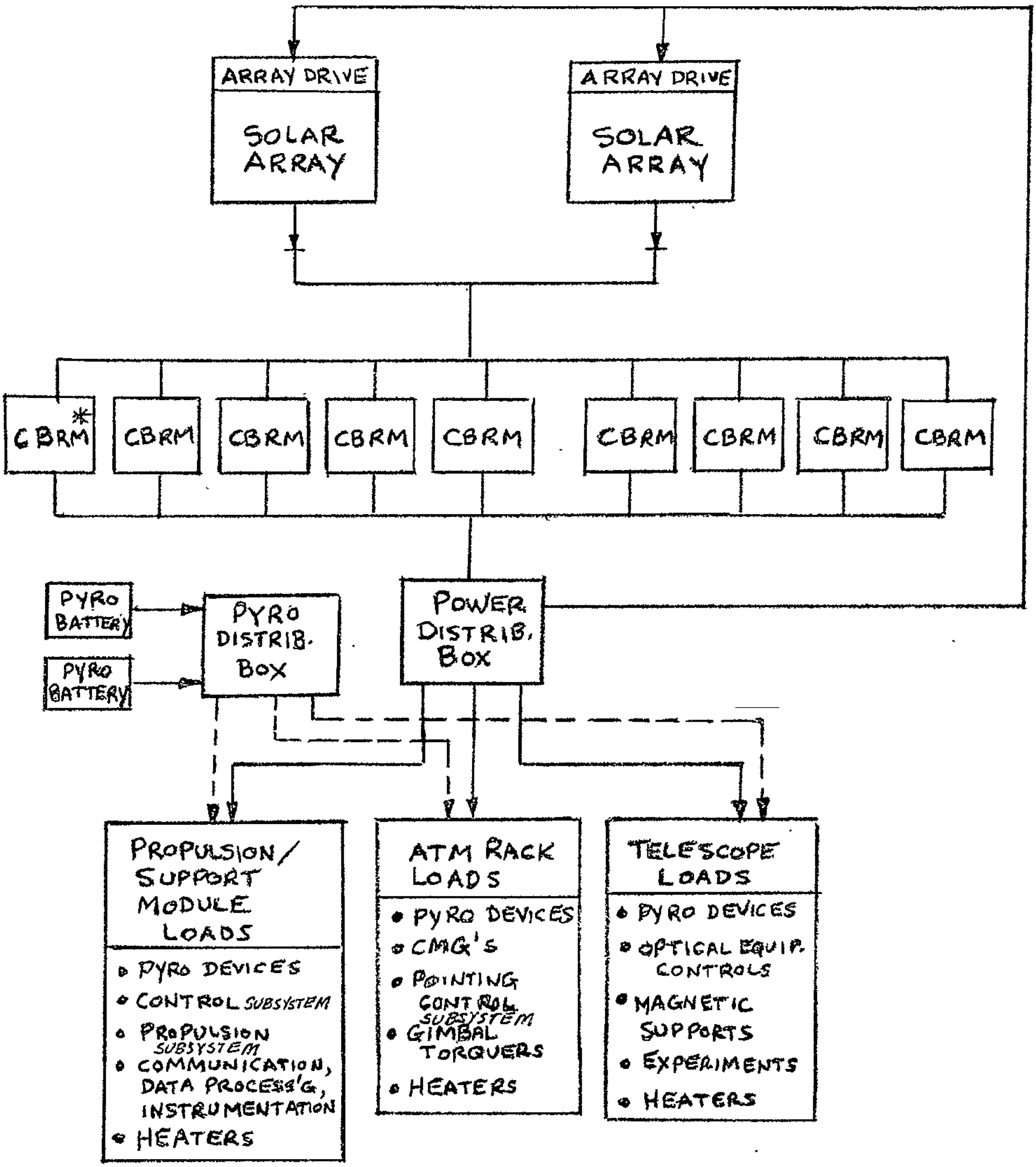

Fig. C-7 LTEP Electrical Power System Block Diagram

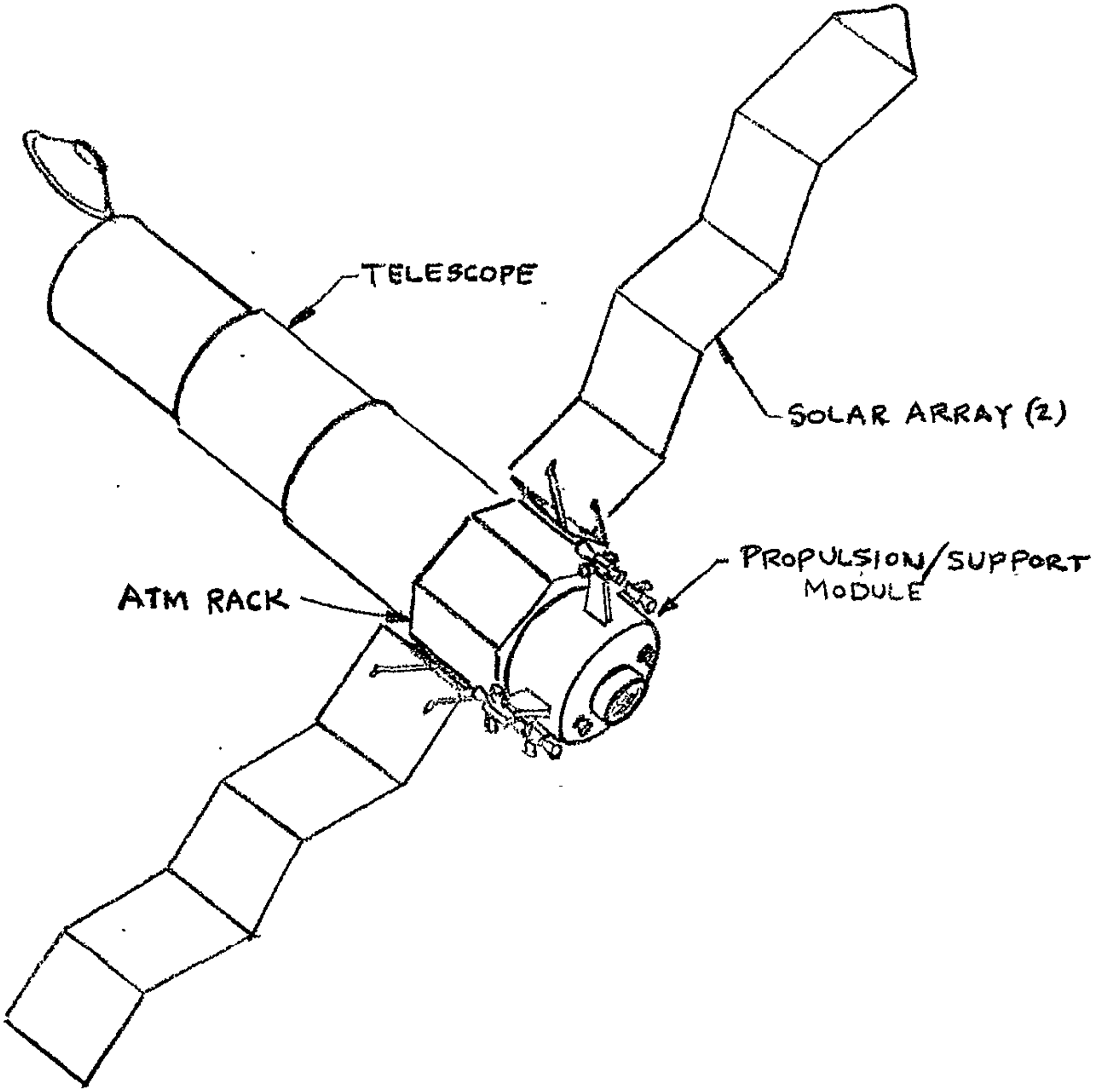

Fig. C-8 Solar Array Configuration for Independent LTEP System

b. Batteries. The batteries used will be rechargeable, non-venting, 20 ampere-hour, 24-cell, and output a nominal 38 volts dc (identical to ATM batteries). Each battery is part of a CBRM (see below). In addition, redundant smaller batteries will be installed to power the pyrotechnic circuits (for actuation of latches, valves, etc.).

The batteries for LTEP usage are required to have an output total of 137 ampere-hours if the discharge depth maximum is limited to 20 percent with an electrical load of 1740 watts:

$$\frac{1740 \text{ watts} \times \frac{36}{60} \text{ hour}}{0.20} = 5200 \text{ WH}$$

for a battery with 38 volt output,

$$\frac{5200 \text{ WH}}{38\text{V}} = 137 \text{ ampere-hour}$$

Utilizing the present ATM 20 ampere-hour battery, seven batteries would be required to satisfy the load. Conservatively, nine batteries have been selected (of the total 18 on ATM).

c. Charger/Battery/Regulator Modules (CBRM's). These modules will control the battery charging cycles and combine solar array and battery power inputs into regulated voltage outputs.

d. System Life Expectancy. The ATM solar arrays should readily withstand two years life on orbit without significant degradation. Because of the characteristics of solar cell deterioration, operation for periods up to five years should be attainable. However, use for operational periods beyond two years should be justified by further testing of samples under simulated conditions and post-flight evaluation of various data and hardware from other long-time orbiting systems.

The type of rechargeable battery chosen is readily capable of operation for a two-year period with discharge-recharge cycling if the depth of discharge does not exceed 30 percent. In the LTEP system, the battery discharge will be between 20 and 25 percent. Operation beyond the two-year period will probably involve one of two approaches:

1. Physical replacement of batteries during manned-maintenance visits;

2. Initial installation in the spacecraft of standby replacement battery packages which can be activated and switched into the power circuit when the first set of batteries deteriorate below a predetermined (and monitored) level.

Assuming implementation of the latter approach, the battery weight would double for a 4-year operational period if "2-year" batteries were utilized. For the LTEP, this would mean about 700 lb increase in launch weight.

e. Electrical System Weights. Table C-3 is a listing of weights for elements comprising the LTEP electrical power subsystem. Items which are part of the existing Apollo ATM electrical system are identified. The total weight of the current ATM Rack electrical has been reduced from 2613 lb to 1636 lb by deletion of equipment not required for LTEP operation, primarily 9 charger/battery/regulator modules at 95 lb each. Some minor repackaging and further elimination of certain redundancies in the ATM system to "tailor" it to the LTEP requirements may be desirable. The feasibility and desirability of this must be determined after a more complete and quantitative analysis of both the LTEP requirements and the ATM electrical hardware design; this analysis should be established for follow-on study effort in Phase B.

C.3.4 AAP Cluster/LTEP Electrical System

The following describes the development of alternate and reduced power requirements for the Cluster/LTEP operation and the basic modifications required in the ATM and OWS/AM electrical systems to accommodate the LTEP.

C.3.4.1 Modified Power Summary. The basic Cluster loads will total 3700 watts (Reference 7-22):

OWS Load		1509 watts
AM Load		966
MDA Load		470
CSM Load		755
	Total	3700 watts

The ATM loads, with the LTEP, have been estimated as:

CMG's		800 watts
Telescope		250
LTEP Subsystems (Control Data Processing)		200
Contingency		100
	Total	1350 watts

The 755 watts shown for the CSM is lower than the 1100 watts estimated by NASA. However, an average of 390 watts will be available from the ATM electrical system, which will have a capacity output of 1740 watts (compared to load of 1350 watts). If required, this additional wattage can be transferred from the ATM to the OWS/AM electrical system thereby providing a total of 390 + 755 = 1145 watts to the CSM.

C.3.4.2 Cluster/ATM Electrical System Modifications. The only changes electrically to the Cluster systems for LTEP application is deletion of two items and addition of disconnects. Two of the four ATM solar arrays will be deleted, thereby reducing the system output from 3480 watts to 1740 watts. Nine of the 18 batteries in the ATM system will also be deleted.

Table C-3

WEIGHT BREAKDOWN – LTEP ELECTRICAL POWER SUBSYSTEM

• ATM Rack Electrical		1636 lb
*Charger/battery/regulator modules (9)	855 lb	
*Control distributors (2)	51	
*Voltage supply measurement (2)	5	
*Measurement distributors (2)	51	
*Selector switch (2)	40	
*Auxiliary power distributor	50	
*Main power distributor	35	
*Power transfer distribution	100	
*Transfer assembly	50	
*J-boxes (12)	24	
*Control/display logic distribution	50	
*Cabling – rack	275	
*Cabling – gimbal	50	
• Solar Array Electrical		2235
*Solar arrays (2)	2035 lb	
Rotation mechanism (2)	200	
• Propulsion/Support Module Electrical		188
Pyro (auxiliary) batteries (2)	120	
Pyro distribution assembly	20	
Voltage controller/regulator	18	
Cabling	30	
• Telescope Electrical		10
Total Electrical Subsystem		4069 lb

*Items identified with an asterisk (*) are from the current Apollo Cluster ATM electrical system.

Additionally, a quick-disconnect must be added in the electrical hard-line between the ATM Rack and the new Cluster swing-links (to accommodate automatic separation of the LTEP Module from the Cluster). Also, a duplicate hard-line interconnect must be routed to one of the MDA radial docking ports. This will provide capability for manual connection by an astronaut (access via docking tunnel) of the mating connector stowed in the docking tunnel of the Propulsion/Support Module of the LTEP Independent spacecraft/telescope.

A simplified block diagram of the Cluster/LTEP electrical power system is shown on Fig. C-9. A more detailed discussion of changes (omissions to) in the ATM electrical system is included in Section C-3.3.c.

C.3.4.3 Solar Array Mechanical Modifications. Because the solar array surfaces must be essentially normal to the sun-line to develop rated power output, it is necessary in the stellar-pointing mode to orient the arrays toward the sun mechanically after a star-field target has been acquired. A single-axis (rotational) movement of the arrays on both the ATM and the OWS, combined with a roll maneuver (about the telescope LOS) of the Cluster/LTEP will provide repositioning of the array surface to a position normal to the sun-line.

To allow usage of the existing ATM and OWS solar arrays, which have solar cells on one side only, a full 360 deg rotation of the arrays is required to accommodate all possible inertial attitudes of the Cluster/LTEP. The existing rotation mechanism on the OWS solar arrays can probably be modified to provide the 360 deg rotation. The two rotatable ATM solar array wings are described in C-3.3.3.

C.4 CONCLUSIONS

The conclusions of the electrical requirements analysis can be summarized as follows:

a. Neither the Cluster/LTEP nor the Independent LTEP can be operated with fixed solar arrays.

b. The lightest-weight solar array concept evolves on the Cluster/LTEP from the use of single-axis pivot (360 deg rotation) on both ATM and OWS solar arrays combined with Cluster/LTEP rotation about the telescope line-of-sight for sun-line aiming of the solar arrays.

c. Use of four solar array wings on the LTEP (ATM), for either Cluster-attached or Independent operation is inefficient. Using two wings and mounting at 90 deg to the longitudinal axis of the Cluster and telescope offers a minimum-weight approach with no shadowing effects.

d. Two of the existing ATM solar arrays combined with nine of the ATM batteries can provide required electrical power for the LTEP in the Independent mode. In the Cluster-attached mode, where the Cluster subsystems are substituting for LTEP subsystems (attitude control, communications, et al), the electrical loads are lower, and some of the wattage can be made available to the Cluster via the existing power transfer devices for supplementing the CSM support power (CSM docked with fuel cells dormant).

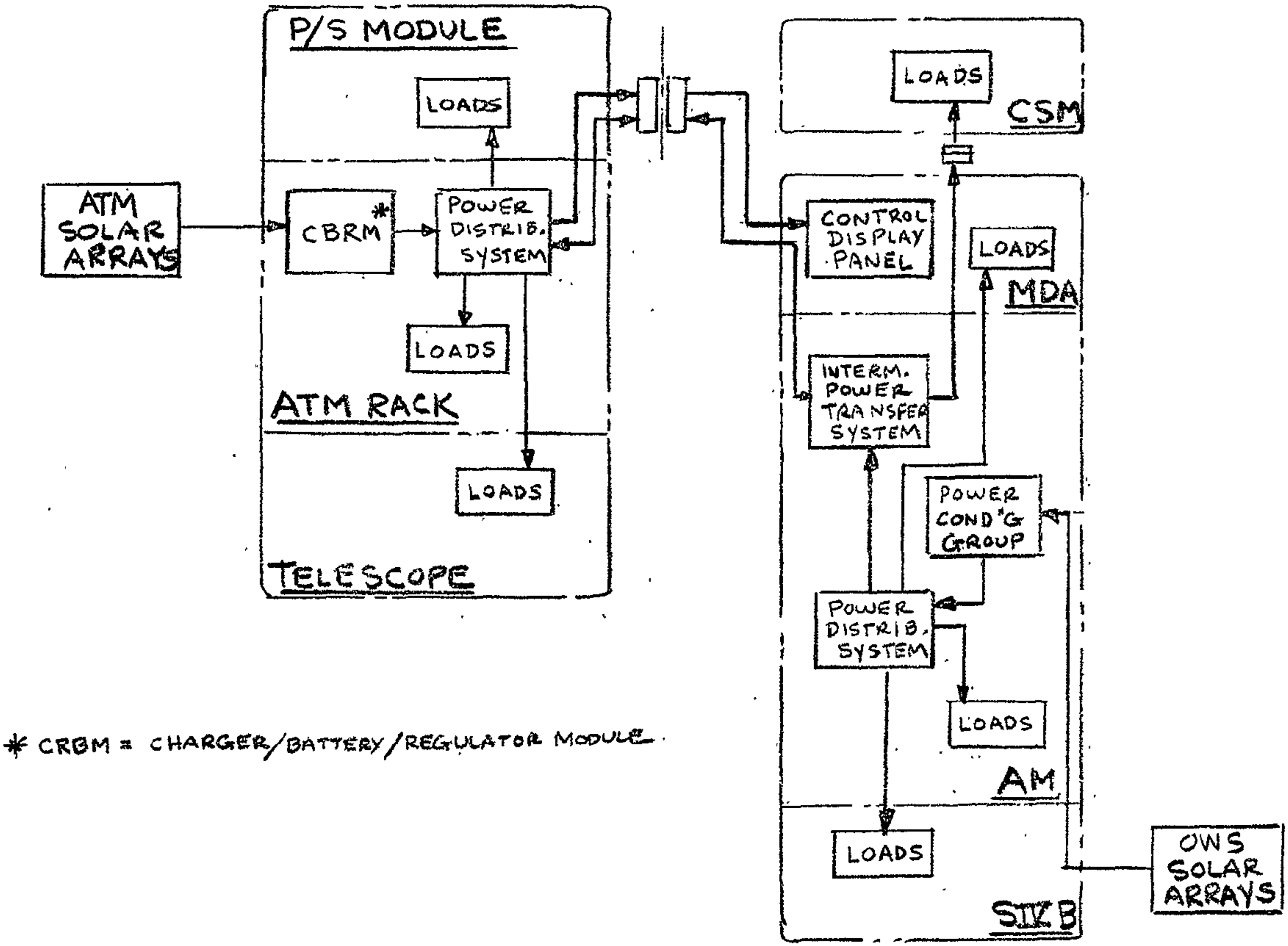

Fig. C-9 Cluster/LTEP Electrical Block Diagram

e. The life expectancy of the proposed solar array/battery system is at least 2 years, limiting the battery discharge depth to a maximum of 30 percent. Extrapolation of operating time beyond that period is difficult because of the small amount of data available on long-term orbit degradation of solar arrays. Actual testing with a simulated environment and analytical review of data and hardware from similar spacecraft programs will be necessary to justify estimates of longer duration operation without replacement.

C.5 RECOMMENDATIONS

It is recommended that the following items be considered for inclusion in follow-on study of the LTEP system:

a. Further investigate the AAP Cluster electrical componentry to determine specific circuitry alterations required in reducing quantities of electrical components for the LTEP system.

b. Evaluate the AAP Cluster componentry (other than solar arrays and batteries) for life-times up to 24 months (existing specifications are for 9 months). Determine critical failure modes and establish hardware redundancy in the "weakest" areas.

c. Establish a preliminary design for a roll-out type solar array and trade-off weight decrease obtained (versus ATM array) with other LTEP program parameters of cost, delivery and hardware confidence.

d. Develop a preliminary design for a 360 deg rotating mechanism for the ATM solar array and establish mechanical interfaces with the solar array and the ATM Rack supporting structure.

e. Develop a preliminary design of a ±180 deg rotation device for the OWS solar arrays. Utilize previous "wet" workshop hardware where possible. Establish mechanical interfaces with the Dry Workshop (SIVB) structure.

APPENDIX D

LTEP COMMUNICATIONS AND INSTRUMENTATION (C&I) SUBSYSTEM REQUIREMENTS

D.1 OBJECTIVE

The objectives of the LTEP C&I analyses were to establish the communication modes and data types and rates for the LTEP system, to analyze the interfaces with the existing MSFN ground network and with the AAP Cluster, and to develop a conceptual design of a communications/instrumentation subsystem for both the Cluster-attached and Independent LTEP operational modes.

D.2 SCOPE

The study covered the following elements:

a. Establishment of mission and orbit limitations upon the availability of MSFN ground stations for LTEP tracking and communication links.

b. Examination of NASA/MSFC data on the Instrumentation and Communication systems of the AAP Dry Workshop Cluster.

c. Determination of specific operating requirements, evaluation of capability of existing equipment to perform LTEP functions, and tentative selection of hardware elements.

d. Conceptual design of a communications and instrumentation subsystem to function in both the Cluster-attached and independent modes.

The results of initial LMSC analyses (Reference 7-11) have been reviewed relevant to the current LTEP system requirements for communications and data processing. The effects of recent changes by NASA/MSFC in implementing the AAP Dry Workshop have been examined; the primary influence on the LTEP system occurs as a result of elimination of the LM Ascent Stage from the AAP Cluster by NASA. This change necessitates the addition of a separate Communications/Instrumentation Subsystem in the LTEP spacecraft to support the telescope in the Independent-orbiting mode.

After examination of mission and orbit restrictions, specific requirements were established for the LTEP Communications and Instrumentation subsystem. The existing AAP Instrumentation and Communication systems (in the AAP Cluster, CSM, and LM) were studied and specific hardware elements selected for use in the LTEP system.

The LTEP Communication and Instrumentation Subsystem was conceptually developed and primary functional characteristics were defined. The interfaces with the AAP Dry Workshop were established.

D.3 RESULTS

D.3.1 Basic LTEP Operating Requirements

Mission and orbit limitations are listed, operational modes described, and general system requirements delineated.

D.3.1.1 Mission Constraints. The LTEP system will have its first flight as early as CY 1974 or 1975. It will be launched, as an experiment attached to the AAP Dry Workshop, on the Saturn V derivative (SIC stage plus SII stage) or as an Independent payload on the Saturn IB (SIB stage plus SIVB stage), or the Titan IIIC. The system will be launched from ETR into a 220 nm altitude circular orbit inclined 35 deg through ETR.

All system elements must operate a minimum of two years and be capable of operating life extension to 10 years by system maintenance or parts replacement (manned operations during rendezvous docking with CSM, Cluster, Space Shuttle, or Space Station).

D.3.1.2 Orbit Limitations. The orbiting LTEP system will be inertially pointed to a stellar target for continuous periods from several hours to as long as four days. The target may be anywhere in the universe except within a cone generated by a 45 deg half-angle about the earth-sun line (Fig. D-1). The orbital period will be about 90 minutes.

D.3.1.3 Ground Station Access. The Manned Spaceflight Network (MSFN) used for the Apollo operations (and other programs) will be used for the AAP Cluster operations or for the Independent LTEP mission. Table D-1 is a summation of the available ground stations listing the data-link capability. This network, or portions thereof, will support the Independent LTEP orbiting system.

D.3.1.4 Operational Modes. The following LTEP operational modes are applicable and will have an effect on subsystem design:

a. Cluster-attached (the SWS-II LTEP) – The LTEP Module will be launched with and attached to the truss-frame and swing links of the Dry Workshop Cluster and located above the MDA within the payload fairing as shown in Fig. D-2. When orbit position has been attained, the LTEP Module is rotated 90 deg, solar arrays and telescope extended as illustrated in the "orbit configuration."

   In launch, ascent, and orbit, communications with earth will be via the Cluster systems. A hardline connection will carry all data from the LTEP Module through the MDA interface to the Cluster.

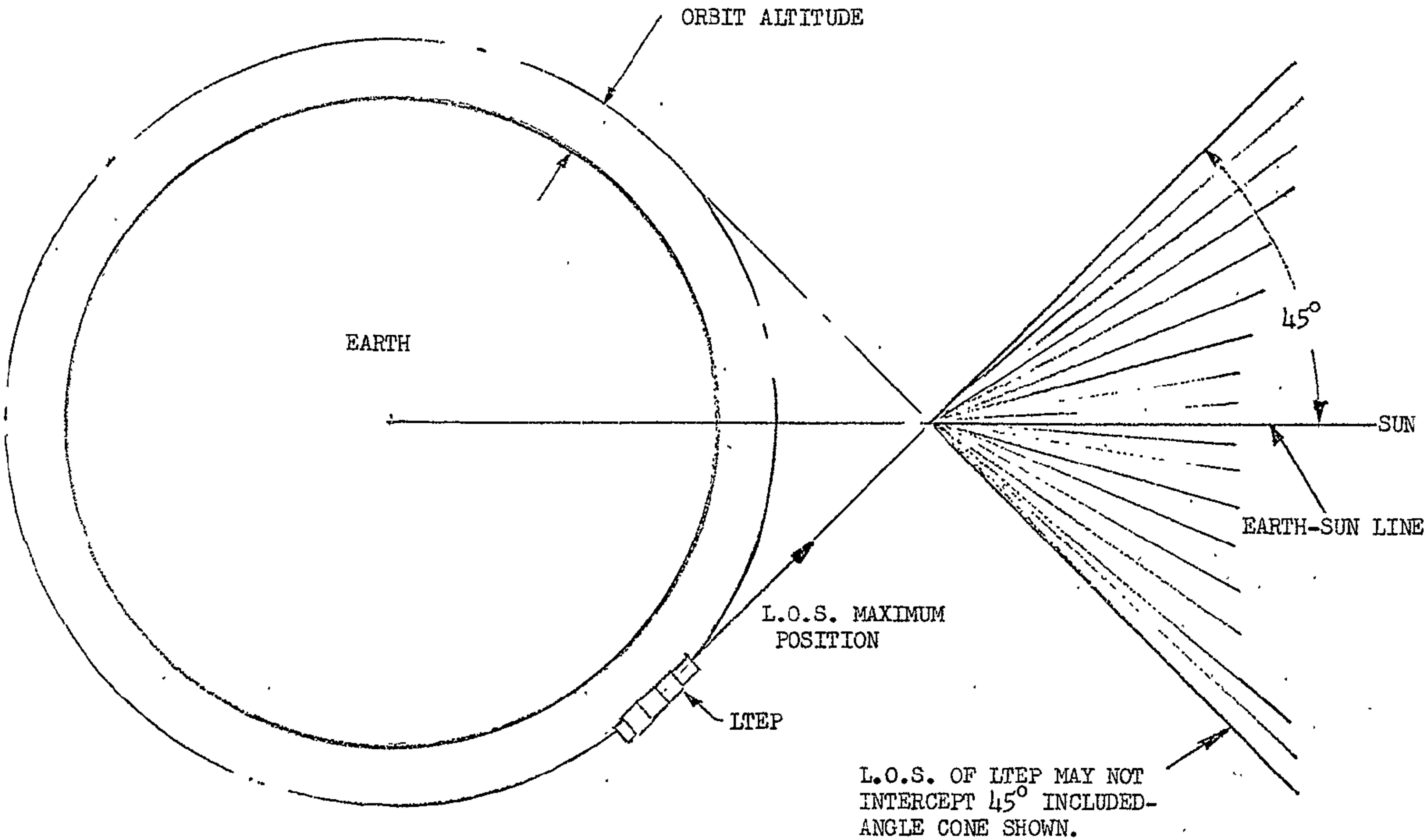

Fig. D-1 Viewing Limits of LTEP

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Table D-1

MSFN STATION SUMMARY

Site	Identification	Unified S-band				C-band Radar TR	VHF TLM	UHF CMD	VHF/AM Voice	*Single/ Dual (Antenna Diameter)
		CMD	TLM	TR	Voice					
1 Cape Kennedy	KSC	X	X	X	X	X	X	X	X	D (30 ft)
2 Grand Bahama	GBM	X	X	X	X	X	X	X	X	S (30 ft)
3 Bermuda	BDA	X	X	X	X	X	X	X	X	S (30 ft)
4 Antigua	ANG	X	X	X	X	X	X	X	X	S (30 ft)
5 Grand Canary	CYI	X	X	X	X	X	X	X		S (30 ft)
6 Ascension	ACN	X	X	X	X	X	X		X	D (30 ft)
7 Madrin Spain	MAD	X	X	X	X					D (85 ft)
8 Pretoria	PRE	(Teletype Only)			X	X	X**			
9 Tananarive	TAN				X	X	X**		X	
10 Carnarvon	CRO	X	X	X	X	X	X	X	X	D (30 ft)
11 Honeysuckle Creek	HSK	X	X	X	X					D (85 ft)
12 Guam	GWM	X	X	X	X		X		X	D (30 ft)
13 USNS Range Tracker	RTK				X	X				
14 Kauai Hawaii	HAW	X	X	X	X	X	X	X	X	D (30 ft)
15 So. Vandenberg	CAL				X	X			X	
16 Goldstone	GDS	X	X	X	X					D (85 ft)
17 Guaymas, Mexico	GYM	X	X	X	X				X	S (30 ft)
18 White Sands	WHS				X	X				
19 Corpus Christi, Texas	TEX	X	X	X	X		X	X	X	S (30 ft)
20 USNS Vanguard	VAN	X	X	X	X	X	X	X	X	D (30 ft)
21 USNS Redstone	RED	X	X	X	X	X	X	X	X	D (30 ft)
22 USNS Mercury	MER	X	X	X	X	X	X	X	X	D (30 ft)
23 USNS Huntsville	HTV		X	X	X	X	X		X	S (12 ft)

*30 ft = 44 db gain; 85 ft = 52 db gain

** Record Capability Only

Ref: 1. TRW Note No. 66-FMT-437, Apollo Mission AS-207/208A Spacecraft Reference Trajectory, 19 Sept 1966
2. "Station Utilization for Apollo Mission AS-207/208A", NASA Memorandum from FC/Chief, Flight Control Division, 21 July 1966
3. "MSFN Capabilities and Implementation for Apollo Missions," NASA Memo from FS/Chief, Flight Support Division, 7 July 1966

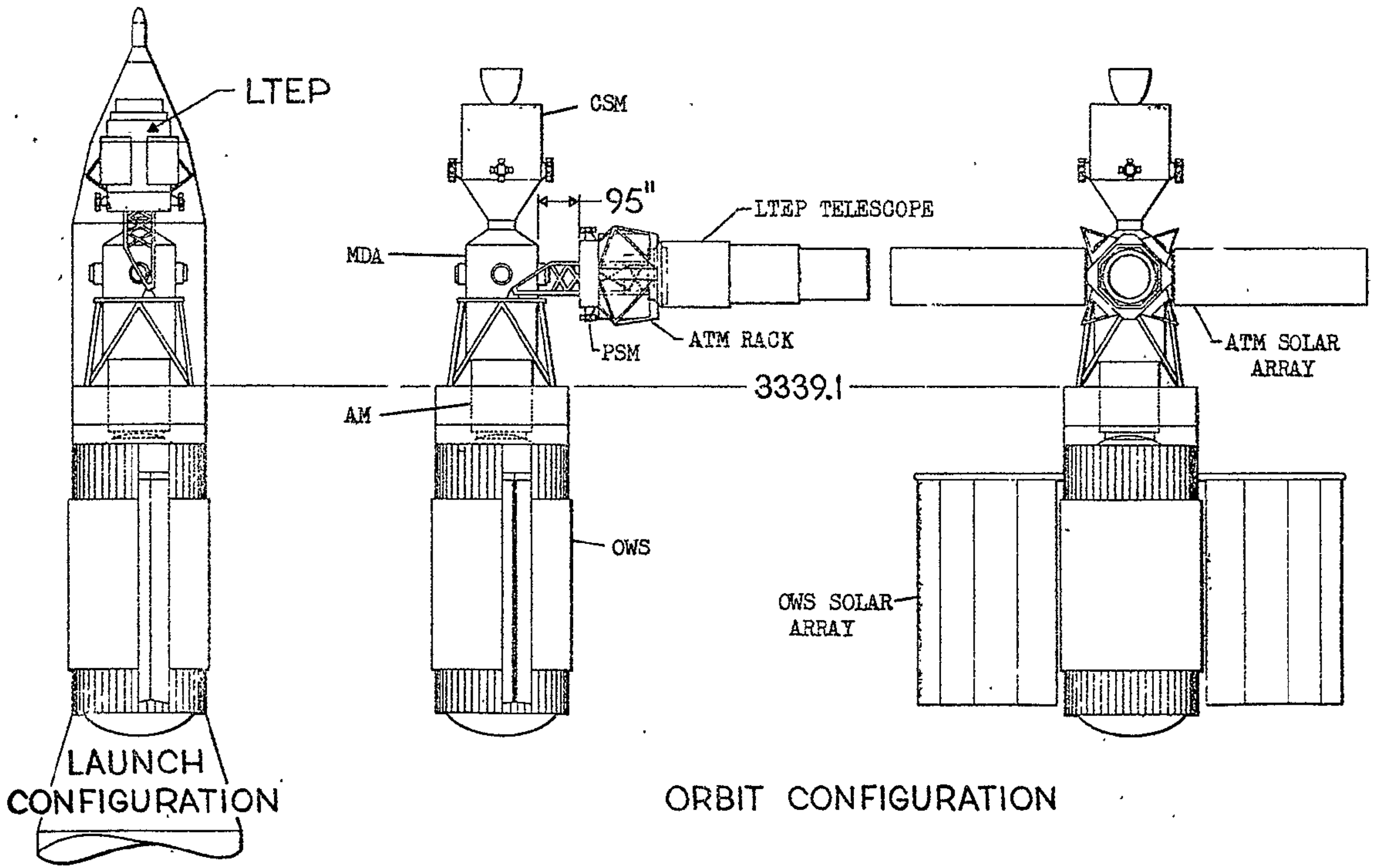


Fig. D-2 Launch and Orbit Configurations of LTEP With AAP Cluster

b. Cluster-Remote (the SWS-II LTEP) – At some time during the Cluster-manned operations or at the end of the Cluster operational period, the LTEP Module will be released from the Cluster. In the free-flight mode, the LTEP system must maintain RF contact with the Cluster and with earth, receiving commands and transmitting data. The LTEP Module must also have transponding equipment aboard to allow ground tracking and commanded rendezvous for redocking to the Cluster.

c. Independent (the Titan IIIC or the Rendezvous LTEP) – The LTEP Module will be launched on the Titan IIIC and be placed in orbit respectively by the SIVB or the Transtage upper stage. During the ascent and initial orbit periods (prior to release from the upper stage), the LTEP system must provide the minimal payload status transmission to earth. After release in orbit, the LTEP will appear as illustrated in Fig. D-3. The CSM will rendezvous and dock for limited time periods for inspection and maintenance by astronauts.

The communications and Data Processing subsystem must:

- Receive, decode, and distribute all ground commands
- Collect, store, convert, and transmit experiment data and support subsystem status to earth
- Provide transponding for earth tracking or rendezvous with CSM.

A hardline connection at the CSM docking port in the Propulsion/Support Module (PSM), which is connected manually by astronaut after CSM docking, will contain safety-monitoring circuits for the LTEP system and certain LTEP subsystem status circuits. Voice communication of astronaut(s) in EVA with CSM will be via umbilical hardline to CSM or via RF from backpack to CSM. The CSM communications system will be "on" during the docked period and all voice down-link will be transmitted by the CSM.

d. Independent with MOTEL (the Saturn IB LTEP) – The LTEP Module, including an added element, the MOTEL life-cell, would be launched into orbit by a Saturn IB in the configuration shown in Fig. D-4. The communications/data processing requirements will be the same as described in D. 3. 1. 4. c except that the hardline to the CSM docking interface will include circuitry for monitoring pressure and temperature within the MOTEL and possibly voice intercom wiring from the MOTEL to the CSM.

D. 3. 2 Existing AAP Cluster Communication and Instrumentation Systems

To provide insight into the Cluster/LTEP interfaces, the pertinent features of the Cluster C&I system are described following.

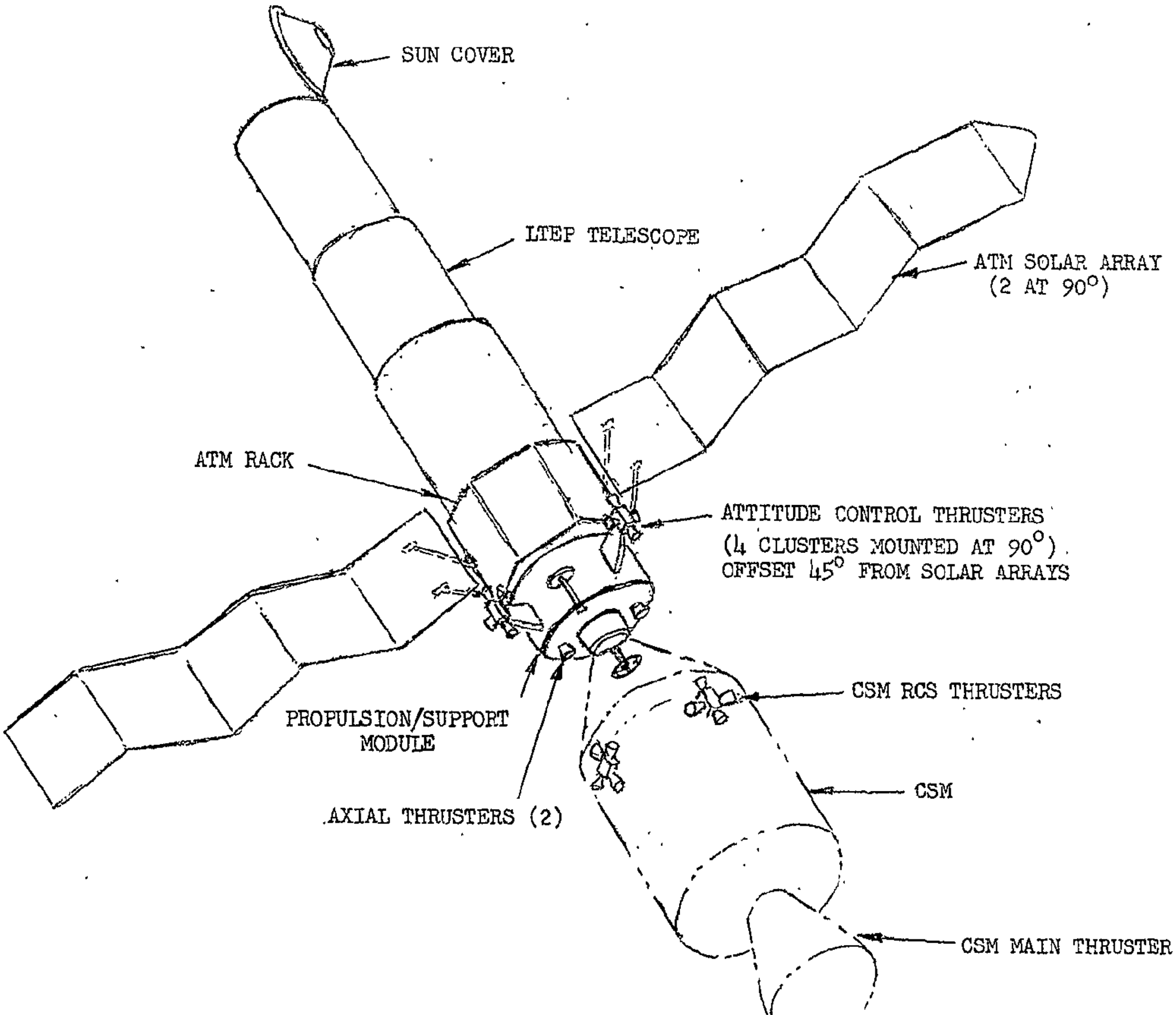


Fig. D-3 Independent LTEP Configuration

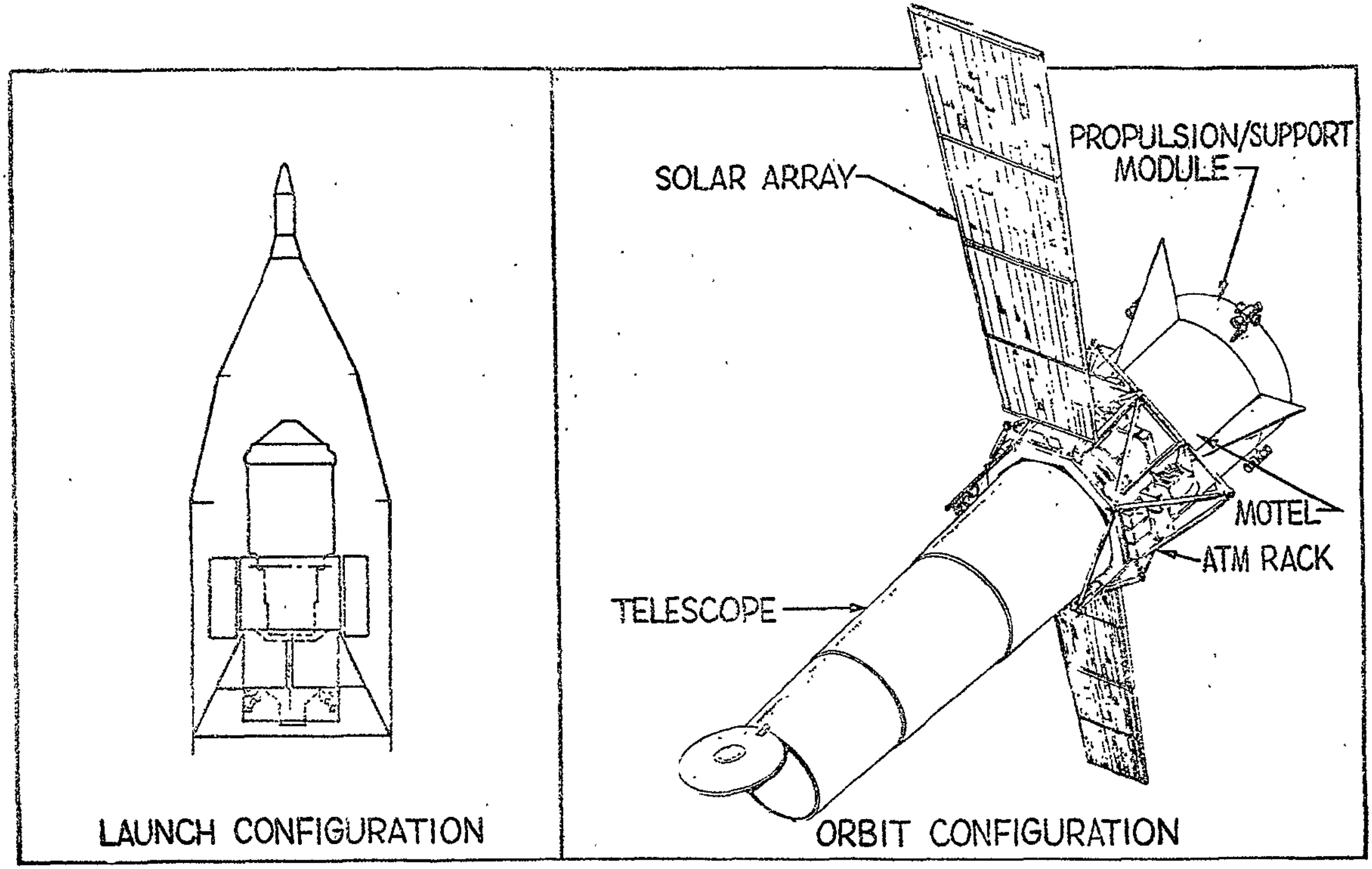


Fig. D-4. Configuration of LTEP Module with MOTEL Life-cell

D.3.2.1 Overall System and Block Diagram. The AAP Dry Workshop Cluster will provide the functions previously performed by the CSM (the CSM is dormant in the current arrangement). Real-time voice, TV, and ranging capability have been added to the AM of the Cluster. Total functions include:

a. Receive and distribute all ground commands.

b. Monitor selected parameters during launch and orbital operations and communicate information to ground stations.

c. Provide tracking data to ground stations.

d. Provide real-time and delayed-time voice communication.

e. Provide a ranging system for rendezvous with CSM.

f. Provide TV communication to the MSFN (small hand-held TV camera).

The quantity of data channels for the Saturn V Workshop Cluster, including experiments, is as follows:

Airlock Module (AM)	499 Parameters
MDA	62
Workshop (OWS)	247
ATM	960
Total	1768

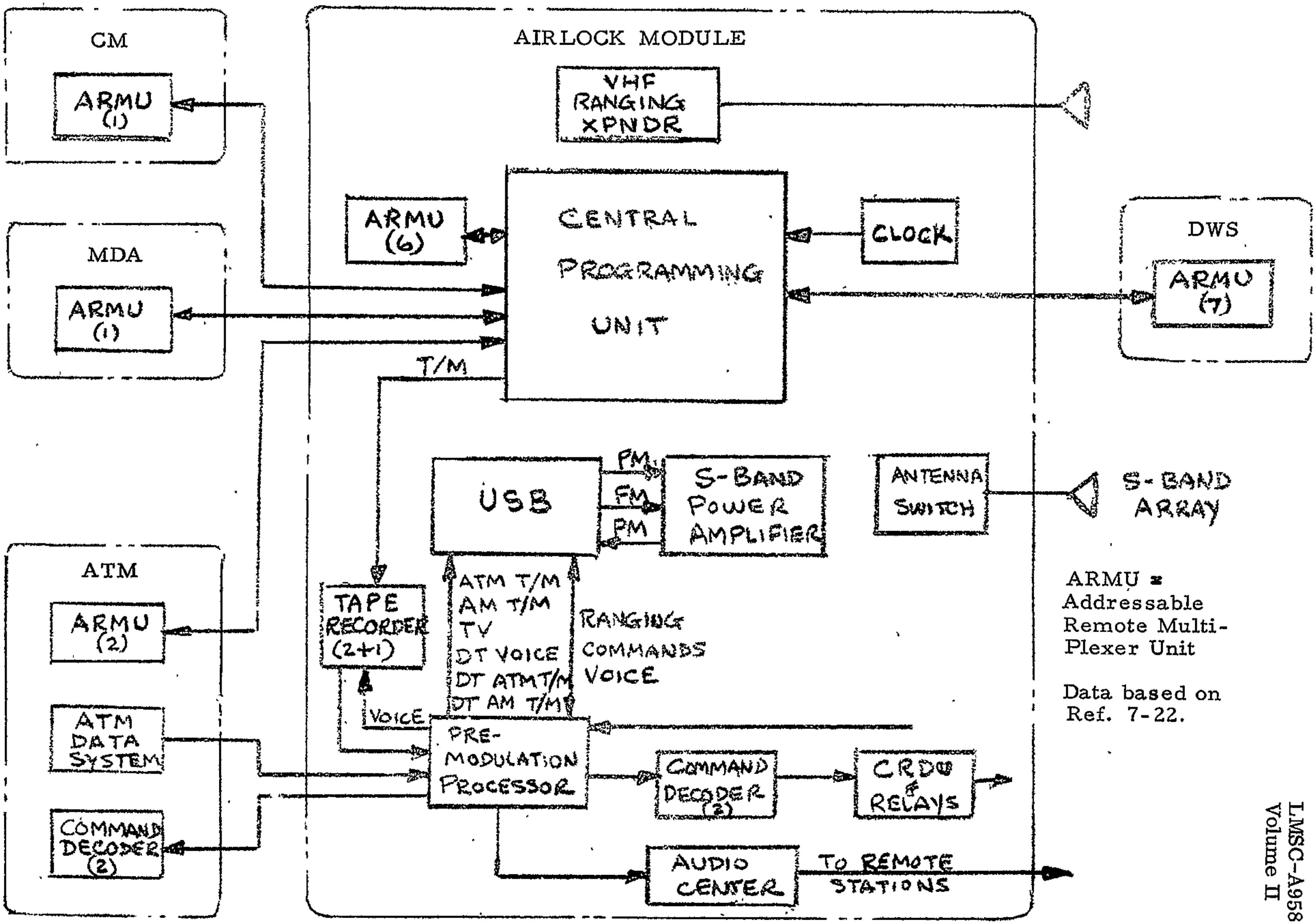
During Cluster storage in orbit, selected parameters will be monitored (about 20 percent of those listed above).

Changes to the previous Saturn I Workshop were:

- Shutdown of CM S-band and audio center after docking
- Elimination of UHF Command and VHF/FM Telemetry
- Simplification in satisfying storage mode and experiment requirements.

The present system is shown in Fig. D-5.

D.3.2.2 Communications System. The Cluster communications system is a duplex S-band system similar to the Unified S-band (USB). Differences exist only in the premodulation processing, which matches the Cluster up and down-link signal characteristics with the USB transponders and transmitters. The precision ranging is integral with the USB and allows active tracking of the orbiting Cluster.



ARMU = Addressable Remote Multi-Plexer Unit

Data based on Ref. 7-22.

Fig. D-5 Saturn V Workshop Communication & Instrumentation System

The Cluster S-band antenna array, similar to the CSM omni antennas, will produce a toroidal-shaped pattern whose axis of symmetry is the longitudinal axis of the Cluster. Switching to individual pairs of antenna elements for desired sector coverage is provided by the attitude control system (ACS) computer.

Frequency utilization of the USB system is:

a. Pulse Modulation (PM) Down-Link

- AM delayed-time T/M
  Ranging } shared
- OWS T/M
- OWS voice

b. Frequency Modulation (FM) Down-Link

- ATM delayed-time T/M
  Delayed-time voice
  TV } shared
- OWS voice (Backup)
- ATM real-time T/M

c. Pulse-Modulation (PM) Up-Link

- Up-voice
- Up-date
- Ranging

D.3.2.3 Data System. The Cluster data system uses multiple format, changeable bit rate, addressable multiplexing techniques. The Central Programming Unit (CPU) converts available addresses to serial digital form outputs. In addition to the addressing functions, the CPU contains input/output circuitry to process data from remote multiplexers and direct inputs, time-correlating these data to form a continuous serial PCM bit stream. The present format content is 51.2 kbps with a word length of 8 bits.

The tape recorder will record two tracks of data; one will record the AM T/M data or experiment data, the other will record voice. The capability will be 160 minutes recording and 5 minute playback. Addressable Remote Multiplexer Units (ARMUs) will be located near the data sources. Each ARMU will interface with the CPU on two pairs of cables, one pair for address and clock and one pair for data return. The ARMUs contain their own power supplies. The number and mix of high-level, low-level, bi-level, digital inputs that each ARMU will contain is flexible with up to 120 analog inputs possible.

The ATM data system utilizes its own T/M and recorders during experiment operation with transmission through the Cluster AM S-band system. During storage and non-experiment periods, ARMUs will provide all ATM data to the CPU in the AM.

D.3.2.4 Command System. The ground command signals modulate a single 70 kHz sub subcarrier on the USB PM carrier and are demodulated in the Cluster. USB unit. The standard 1 kHz and 2 kHz signals are provided to the AM and ATM decoders.

D.3.2.5 TV. Provision is made only for one portable hand-held TV unit. The analog TV signal will modulate the non-coherent FM carrier in the USB on a time-shared basis with delayed voice.

D.3.2.6 Rendezvous Ranging. A VHF/AM ranging system is provided in the Cluster to allow turn-around of the CSM ranging tones. Hardware comprises VHF antenna, VHF/AM transceiver, and a range tone transfer assembly.

D.3.3 LTEP Communications and Instrumentation Subsystem

The special requirements for the subsystem, an evaluation of potential application of available hardware, and a description of the LTEP Communications and Instrumentation subsystem have been developed.

D.3.3.1 Special Requirements. A few specific requirements must be satisfied by the LTEP subsystem.

a. Data Dump to Ground Stations. The total time available to transmit data to a ground station is a variable. The contact time for a particular station usually exceeds four minutes and is frequently in excess of seven minutes (values for the 220 nm orbit will be similar).

b. Bit Rate Capability. The Apollo-type system will have capability of transmitting data to earth at a rate of 51.2 kbps.

c. TV Transmission. It is assumed that completed pictures of stellar fields will be transmitted to earth. It is estimated that 50 to 100 lines per mm is adequate to reproduce a 12th magnitude star. A sample calculation follows for transmitting by TV a 2-1/4 x 2-1/4 inch photo format:

- $\left(\frac{100 \text{ lines}}{\text{mm}}\right)\left(\frac{25.4 \text{ mm}}{\text{inch}}\right)\left(\frac{2.25 \text{ inch}}{\text{frame}}\right) = 5715 \text{ lines/frame}$

- To attain similar horizontal resolution, at 5000 elements per line,

$$\text{Total elements per frame} = 25 \times 10^6$$

- A 14-level grey scale has been chosen requiring 4 bits per element:

$$(25 \times 10^6 \text{ elements/frame}) \text{ (4 bits/element)} = 10^8 \text{ bits/frame}$$

- For a 3 minute transmission time,

$$(10^8 \text{ bits/frame}) \div (180 \text{ sec}) = 555,555 \text{ bps}$$

The following transmission typical schedule is offered for a contact total time of 4 minutes:

- 30 sec – acquisition and initial command
- 10 sec – transmitter warmup
- 180 sec – transmission
- 20 sec – closing command

D.3.3.2 Subsystem Description. A brief description of the LTEP Communications and Instrumentation subsystem follows. It comprises a functional description, an equipment list, and installation/location information.

a. Subsystem Functions. Figure D-6 illustrates the data flow in the C&I subsystem. It is similar to the installation in the AAP Cluster and, in fact, uses certain of the packages currently in the Apollo CM. Its functions will be:

   - Receive data and commands from earth, decode, and distribute to internal units.
   - Perform transponder function for tracking and rendezvous.
   - Collect, store, convert, and transmit to earth, experiment data and subsystem status.

   All up-link data will be received at 2100-2110 MHz. Down-link data will be transmitted on PM at 2287.5 MHz; TV only will be transmitted FM at 2277.5 MHz.

b. Equipment List. Table D-2 is a preliminary equipment list of elements comprising the LTEP C&I subsystem. It is assumed that the TV Camera will be supplied as part of the optical experiment package; it is listed for reference only.

c. Subsystem Installation. The various components of the C&I subsystem will be installed in the LTEP Propulsion/Support Module (PSM) in temperature-controlled equipment compartments.

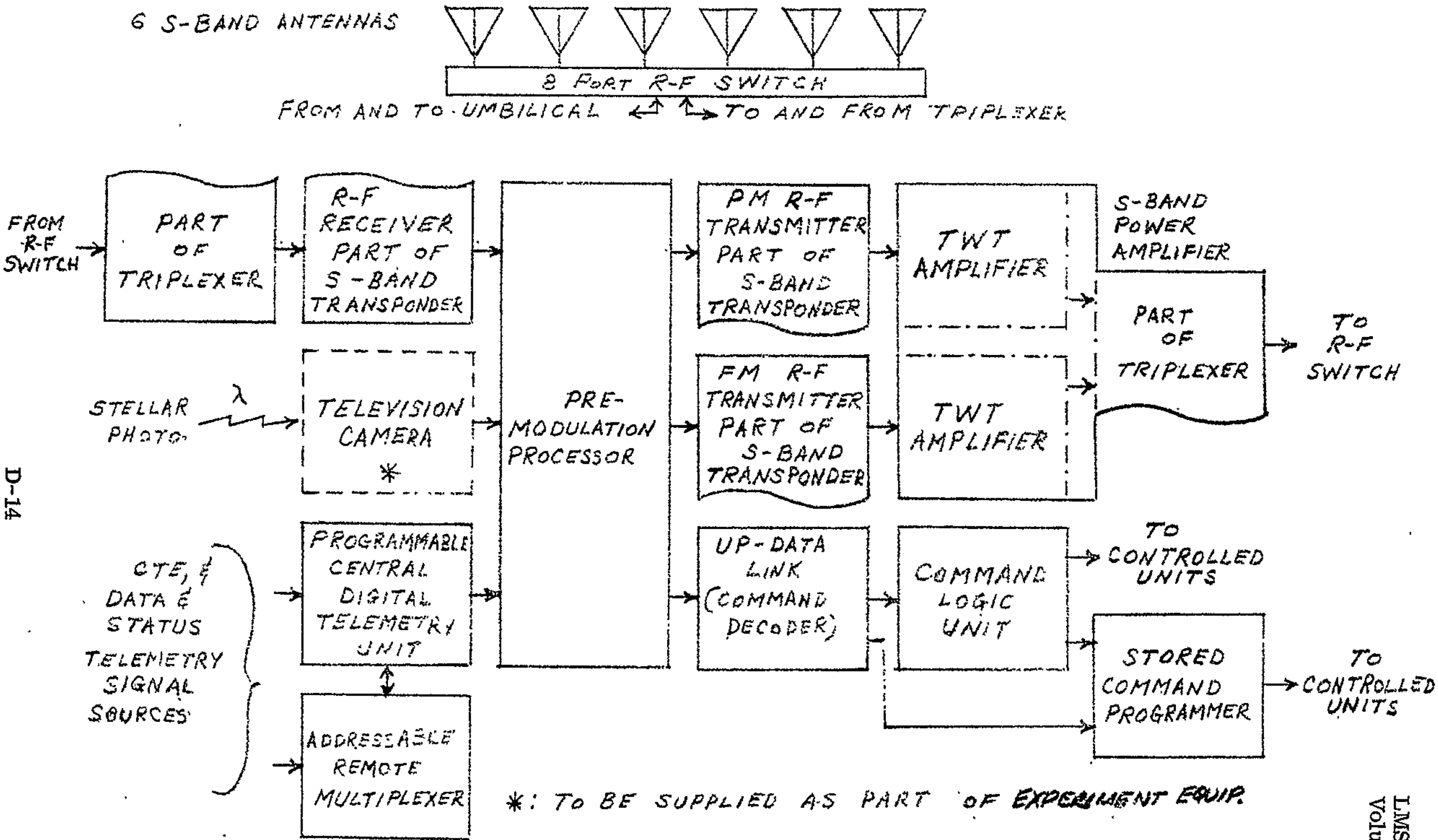


Fig. D-6 LTEP Communications and Instrumentation Subsystem Block Diagram

Four of the omni antennas, each with a 125 deg solid-angle electromagnetic radiation pattern, will be mounted on the exterior of the PSM. Three will be mounted equally-spaced on the cylindrical shell; the fourth will be mounted on the bottom plate of the module. The other two antennas will be mounted on short booms with the axis of the pattern parallel to the telescope line-of-sight; they will have a 65 deg solid-angle pattern. The six antennas will provide a 4π solid-angle coverage with selectable section coverage (by use of an antenna selector switch command).

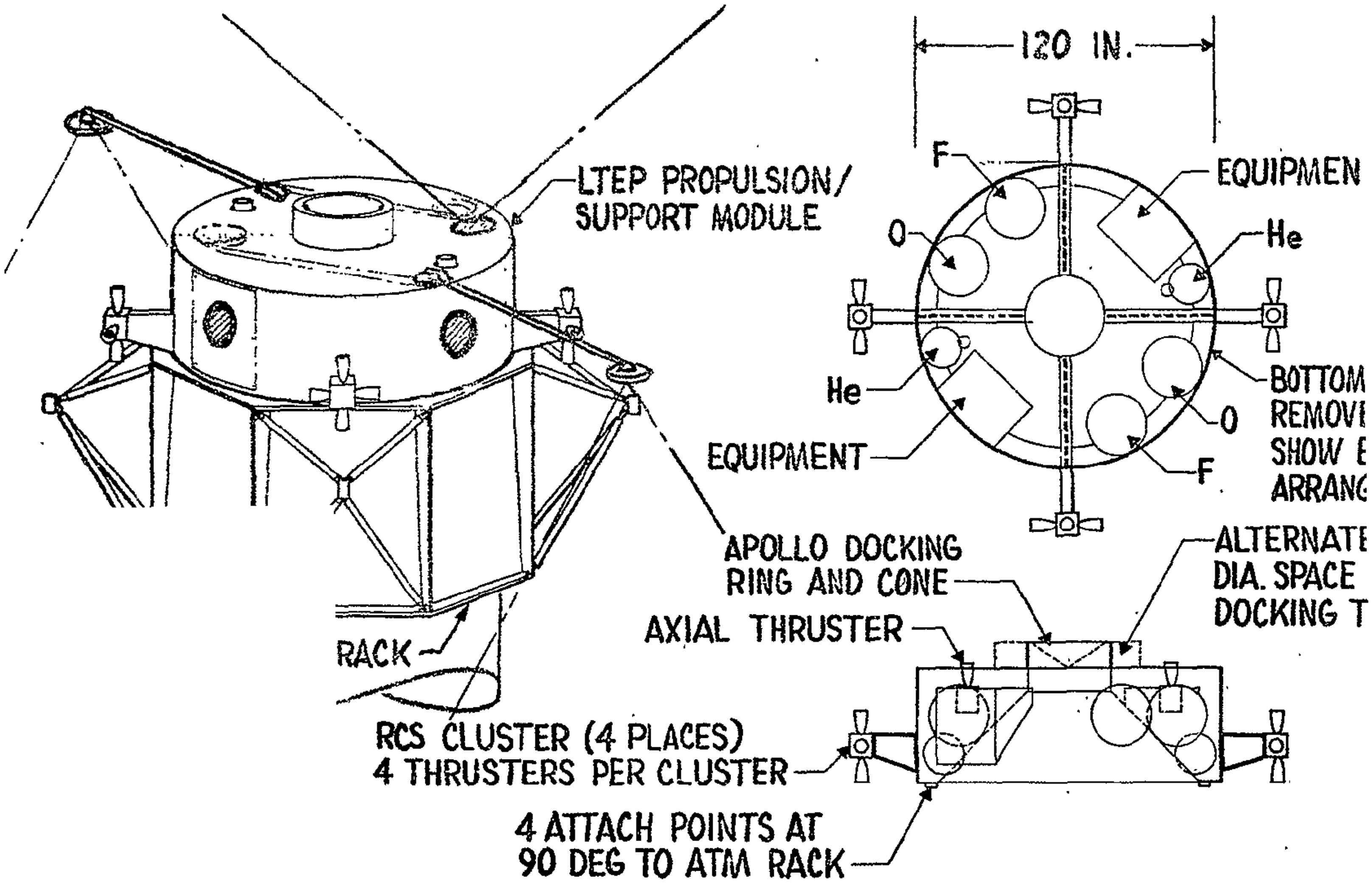
Figure D-7 is an illustration of the PSM showing the equipment compartment locations and the antenna positions. The stowed position of the two boom-antennas are shown in phantom-line on the bottom of the PSM.

Table D-2

EQUIPMENT LIST – LTEP COMMUNICATIONS AND INSTRUMENTATION

Item	Vehicle Qty	Total Wt (lb)	Used On Program Previously
Antenna-cavity backed spiral	6	6.0	New
Boom-Antenna	2	4.0	New
Switch-RF – 8 port	1	3.5	New
Transponder – unified S-band	1	33.0	Apollo CM
Telemetry unit – digital-programmable central	1	16.0	LMSC
Multiplexer – addressable remote	1	9.0	LMSC
Premodulation processor	1	14.5	Apollo CM
Up-data link (command decoder)	1	20.6	Apollo CM
Command logic unit	1	12.0	LMSC
Programmer – stored command			
Amplifier-triplexer assy-TWT-S band			
Subsystem interconnect cabling			
(Camera – TV)*			
TOTAL SUBSYSTEM			

*TV camera is shown for reference only. W al for experiment packages.



opulsion/Support Module and Communications/Instrumentation Installation

D.3.3.3 Evaluation of Existing Equipment Capability. The LTEP C&I subsystem requires no development of new concepts. A few of the tentatively selected components will require minor modification to adapt them to the LTEP system.

Designs for the S-band antennas are in existence. Matching to the LTEP vehicle will be necessary. Each is a cavity-backed spiral type (approximately 3-inch diameter by 1.5 inches deep) with a gain of 3 db relative to an isotropic radiator.

Components developed for the Apollo CM have been selected to minimize new development costs. Their relatively short-rated operating life (200 hours) has been considered in conjunction with their relatively good mean-time-between-failure rating (50,000 hours). The units selected are:

- S-band transponder
- Premodulation processor
- Up-link data equipment (command decoder)
- S-band power amplifier

The remainder of the existing components were selected on the basis of relatively longer life rating (18 months operating "life," including ground-testing; 6 months orbital life rating; 720 continuous hours rated) and actual long-life operating experience in military programs. The programmer has a rated 9 months orbital life. These components are:

- Programmable central digital telemetry unit
- Addressable remote multiplexer
- Command logic unit
- Stored command programmer

A brief supplier survey for a 5000-line per frame resolution TV camera (most scientific data TV cameras have 875-1800 lines per frame) and a scan rate of one frame (10^8 elements) per six minutes revealed that RCA has a 4-1/2-in
Vidicon (RBV) developed for earth resource
vide the required resolution. Follow-up on
anticipated Phase B effort.

D.3.3.4 Life Expectancy Survey. Because
at 200 hours of operating life (far below the
with NASA/MSFC to determine the actual ca
ing information was obtained:

a. Previous experience has been ess ich
are required to operate during sho onger
operating life will have to be cons

b. No life test has been performed on the short-life-rated Saturn articles. Reliability predictions are used.

c. AAP Workshop time schedules do not provide time for new development; henc existing units must be modified to attain added life requirement.

In summary, operation of existing equipment for periods up to two years is currently not validated by analysis, prior equipment testing, nor by actual operating experience.

It will be necessary, in follow-on efforts on the LTEP system, to meticulously examine all hardware designs and associated test and operating data in an attempt to realistically extrapolate the 200 hours and 6 or 9 months "specification" life times to longer periods. Additionally, component stand-by redundancy can be employed with automatic shift-over to a "replacement" component when the initial unit fails. Hopefully, a considerable amount of correlatable life data will be forthcoming during the next two years as the Apollo Applications Programs are extended from the current 13 days to 26 and then to 56 days or longer (with intermittent dormancy periods extending the required life to 9 months).

D. 3.4 AAP Cluster/LTEP Communications and Instrumentation System

The NASA-planned Dry Workshop Cluster C&I system is described in Section D. 3.2. Except for lack of capability to transmit high-resolution (up to 5000 lines per frame) TV data to ground stations, it is capable of handling all requirements of the LTEP system.

In the mode where the LTEP Module is attached to the Cluster and hard-line-connected into the MDA, all up-link data receiving and down-link data transmitting will be accomplished by the Cluster system. Detailed command decoding and data conversion or multiplexing for the LTEP telescope and experiment packages will be accomplished by the LTEP system elements and received/transmitted hard-line via the ATM Rack.

Because the LTEP system must be capable of Independent operation after separation from the Cluster, the complete LTEP C&I subsystem must be installed in the LTEP Module even for Cluster-attached operation. Switchover circuitry will be provided to automatically switch to the "Independent mode" when the hard-line connection to the Cluster is opened during separation from the Cluster. Redocking to the Cluster and reconnection of the hard-line would reverse the operation and the Cluster would again become the primary data receiving/transmission element of the co

D.4 CONCLUSIONS

The currently planned AAP Dry Workshop Clu
for handling all of the LTEP system communi
the exception of the TV network. If it is plan
lines per frame) reproduction of stellar-field

multiplexer quantizer element would be added to the existing circuitry to allow pulse-coding and digital transmission of high bit-rate data. The current Cluster system handles the TV (small hand-held camera) on analog.

The proposed LTEP Communication and Instrumentation Subsystem comprises a number of existing components which are space-flight qualified. Some are from the Apollo CM system, the remainder are from spacecraft produced by LMSC. A primary potential problem exists in selection of proven hardware. Most of the Apollo program hardware was designed and tested to a 200-hour operating-life specification. The described program hardware, in most cases, is designed and tested to either a 6-month or a 9-month operating life specification. Many of these hardware elements are probably capable of longer operating periods, but there is presently no validation of this capability by analysis, testing, nor operating experience. With the two-year minimum life required by the LTEP system, and considering the potentially large benefits of using proven hardware (even with shorter operating life), it appears mandatory that a strong effort should be initiated to investigate, in detail, the long-life expectancy of the available hardware tentatively selected for the LTEP system (or equivalent).

The Manned Space Flight Network (MSFN) ground stations to be utilized with the AAP Cluster are adequate also for the Cluster/LTEP and Independent LTEP orbiting systems. Ground contact periods per station will vary from 4 to 8 minutes, quite sufficient for the LTEP system (or Cluster/LTEP) data dumps.

D.5 RECOMMENDATIONS

Because space-qualified hardware compatible with S-band operations with the MSFN are available for use in the LTEP Communications and Instrumentation Subsystem, a large potential savings in LTEP development cost exists. However, considerably more proof is needed that these hardware elements are capable of operation for the two-year period of the LTEP system. It is recommended that a high-priority follow-on study task be initiated to: (1) investigate the designs and functional characteristics; (2) analyze previous test results and operating reports; (3) evaluate the probability of extended life operation in the LTEP system environment; and (4) recommend modifications to components or standby redundant installations to provide the two-year life capability in the subsystem.